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THE UNIVERSITY OF ALBERTA

REGIME RELATIONS IN A GRAVEL REACH OF THE RED DEER RIVER, ALBERTA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

by

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EDMONTON, ALBERTA

SEPTEMBER 1962

ABSTRACT

(a) The frequency distribution of river bed stone size from the largest to one tenth the largest was found, to a good degree of approximation, to be logarithmic normal, whether in terms of number of stones or weight of stones in a sample.

(b) Over the small size range available, equivalent spherical diameter varied, on an average, directly as triaxial size (thickness); $\phi = 1.55 \propto$.

(c) Median size of stone by weight approximated 1.8 times that by number.

(d) In terms of somewhat subjectively determined values of F_{bo}, obtained from analysis of low-flow data, values of λ were calculated in the empirical formula $F_{bo} = \sqrt[3]{\lambda D_{mi}}$, where D_{mi} is the equivalent spherical diameter in inches of the median stone size by weight.

(e) Using low flow slope data and assuming negligible bed-load charge the steepest river reaches in 24.5 miles gave meander coefficients (for slope) consistent with general belief provided F_{bo} was of the order of size suggested by Dr. Blench.

(f) Confirming Bhattacharya's experiments on 1.7 mm. gravel in a laboratory flume, using a larger apparatus, it was found that F_{bo} dropped from about 4.3 with a discharge intensity of 0.67 cfs./ft. to about 1.2 at 1.9 cfs./ft. The corresponding $D_{mi}/12d$ ratios are 0.012 and 0.0039.

ACKNOWLEDGEMENTS

The author wishes to express his many thanks to the various people who co-operated in the research project on which this report is based; to the Alberta Water Resources Department, who initiated, supported and financed the project; to Dr. T. Blench, Professor of Hydraulics at the University, who took a very keen interest in the project and gave much valuable advice, criticism and encouragement all the time, his painstaking work as editor was indispensable; to Mr. R.E. Bailey and Mr. R.K. Deeprose for their valuable advice, criticism and continual encouragement; Mr. I. Anderson, Mr. Joe Ploeg, Mr. Steve Vida and other engineers of the Alberta Water Resources and Mr. A.W. Peterson, who gave much guidance in the auxilliary flume experiments in the Hydraulics Laboratory of the University of Alberta, and Mrs. Georgina Allison for helping in typing.

Finally it is necessary to thank many friends and professors of the University for their moral support.

M.A. QURESHI.

REGIME RELATIONS IN A GRAVEL REACH OF THE RED DEER RIVER, ALBERTA

TABLE OF CONTENTS

		Page
Abstract		(i)
Acknowledgements		(ii)
List of Tables		(vi)
List of Figures		(vii)
CHAPTER I - INTRODUCTION		
1.1.	Introduction, definitions	1
CHAPTER II - THE SIZE DISTRIBUTION OF RIVER BED GRAVEL		
2.1.	Introduction	6
2.2.	Wolman's method for sampling coarse river-bed material	7
2.3.	Method of sampling Red Deer River bed gravel	8
2.4.	Limitations of the sampling method	9
2.5.	Precautions taken while sampling	9
2.6.	Measurements of the stone size	9
2.7.	Formula for equivalent spherical diameter	9
2.8.	Relation between equivalent spherical diameter and thickness	10
2.9.	Description and frequency analysis of samples	10
2.10.	Details of stone samples	11
2.11.	Relation between median thickness of a stone in a sample by number and that by weight	12
2.12.	Determination of median equivalent spherical diameter from the actual weight of stones	12
2.13.	Description of the bed load material sampling with sieves by Water Resources Engineers	12
2.13.1.	Detailed procedure	12
2.14	Analysis of samples by sieves	13

		Page
2.15.	Definition of median diameter of active gravel bed for regime calculations	14
CHAPTER III - REGIME SLOPE ANALYSIS		
3.1.	Introduction	15
3.2.	Programme for collection of data	16
3.3.	Collection of data	17
3.3.1.	Cross-sections	17
3.3.2.	Discharge measurements	17
3.3.3.	Photographs	18
3.3.4.	Profile	18
3.3.5.	Suspended load sampling	19
3.4.	Summary of the regime slope formulas	19
3.5.	Use of slope formulas for a river	19
3.6.	Procedure for determination of meander coefficients	21
3.7.	Sample calculation of k	22
3.8.	Determination of charge at high flow	23
3.9.	A sample calculation of charge	23
3.10.	Relation between median size of bed-load material and zero bed factor	23
CHAPTER IV - AUXILLIARY FLUME EXPERIMENTS		
4.1.	Introduction	24
4.2.	Description of the apparatus	24
4.3.	Procedure	25
4.4.	Measurements recorded	25
4.4.1.	Measurements of depths	25
4.4.2.	Discharge	25
4.5.	Observations	25
4.6.	Analysis of experimental results	25

	Page
CHAPTER V - SUGGESTIONS FOR FUTURE RESEARCH	27
REFERENCES:	28
APPENDIX 'A': List of Symbols	29
APPENDIX 'B': Tables	30 - 54
APPENDIX 'C': Figures	55 - 192

LIST OF TABLES

		Page
1.	Stone measurements, sample No. 1	30
2.	Stone measurements, sample No. 2	33
3.	Stone measurements, sample No. 3	34
4.	Stone measurements, sample No. 4	37
5.	A sample of calculations for analysis of bed-load sample No. 4	39
6.	Results of analysis of size distribution of gravel.	44
7.	Results of sieve analysis of composite sample	45
8.	Meander coefficients for steep sections	46
9.	Values of charge for various floods, as assessed from the regime slope formula	48
10.	Values of λ in the formula $F_{bo} = \sqrt[3]{\lambda D_{mi}}$ for $F_{bo} = 4.0$	49
11.	Measurements and observations made in the flume experiment	50
12.	Calculations for the analysis of flume experiment data	54

LIST OF FIGURES

		Page
1.	Aerial photograph (3333' = 1") showing the Red Deer River	55
2.	Aerial photograph (3333' = 1") showing the Red Deer River	56
3.	Aerial photograph (3333' = 1") showing the Red Deer River	57
4.	Aerial photograph (3333' = 1") showing the Red Deer River	58
5.	Frequency curve of maximum annual peaks for Red Deer River at Red Deer	59
6.	Blench's plot of dimensionless size distribution curve for two sand samples taken from Strait of Georgia up Fraser River, B.C., Canada	60
7.	Wolman's curve for size analysis of river-bed gravels	61
8.	Sketch showing length, breadth and thickness	9
9.	Plot of ϕ against $\propto$ for sample of bed gravel at cross-section A_3	62
10.	Plot of ϕ against $\propto$ for A_4	63
11.	Plot of ϕ against $\propto$ for A_5	64
12.	Plot of ϕ against $\propto$ for A_6	65
13.	Plot of ϕ against $\propto$ for A_3, A_4, A_5 and A_6	66
14.	Plot of size distribution curve for $\propto$ by number for A_2	67
15.	Plot of size distribution curve for $\propto$ and $\propto/\propto_{50}$ by weight for A_2	68
16.	Plot of size distribution curve of ϕ by number and weight for A_3	69
17.	Plot of size distribution curve of ϕ/ϕ_{50} by number and weight for A_3	70
18.	Plot of size distribution curve of ϕ for A_4	71
19.	Plot of size distribution curve of ϕ/ϕ_{50} for A_4	72
20.	Plot of size distribution curve of ϕ for A_5	73
21.	Plot of size distribution curve of ϕ/ϕ_{50} for A_5	74
22.	Plot of size distribution curve of ϕ for A_6	75
23.	Plot of size distribution curve of ϕ/ϕ_{50} for A_6	76
24.	Plot of size distribution curve of $\propto$ for A_7	77
25.	Plot of size distribution curve of $\propto/\propto_{50}$ for A_7	78
26.	Plot of size distribution curve of $\propto$ for A_8	79
27.	Plot of size distribution curve of $\propto/\propto_{50}$ for A_8	80

LIST OF FIGURES - cont'd.

		Page
28.	Plot of size distribution curve of $\propto$ for A_9	81
29.	Plot of size distribution curve of $\propto/\propto_{50}$ for A_9	82
30.	Plot of size distribution curve of $\propto$ for A_{10}	83
31.	Plot of size distribution curve of $\propto/\propto_{50}$ for A_{10}	84
32.	Plot of size distribution curve of $\propto$ for A_{11}	85
33.	Plot of size distribution curve of $\propto/\propto_{50}$ for A_{11}	86
34.	Plot of size distribution curve of $\propto$ for A_{12}	87
35.	Plot of size distribution curve of $\propto/\propto_{50}$ for A_{12}	88
36.	Plot of size distribution curve of $\propto$ for A_{29}	89
37.	Plot of size distribution curve of $\propto/\propto_{50}$ for A_{29}	90
38.	Plot of size distribution curve of $\propto$ for A_{30}	91
39.	Plot of size distribution curve of $\propto/\propto_{50}$ for A_{30}	92
40.	Plot of size distribution curve of $\propto$ for A_{31}	93
41.	Plot of size distribution curve of $\propto/\propto_{50}$ for A_{31}	94
42.	Plot of size distribution curve of $\propto$ by number for $A_{2, 7, 8, 9, 10}$ & 30	95
43.	Plot of size distribution curve of $\propto$ by weight for $A_{2, 7, 8, 9, 10}$ & 11	96
44.	Plot of size distribution curve of ϕ by number for $A_{3, 4, 5, 6}$	97
45.	Plot of size distribution curve of ϕ by weight for $A_{3, 4, 5, 6}$	98
46.	Plot showing relation between $\propto_{50}$ by weight and $\propto_{50}$ by number	99
47.	Plot of bed sample weight distribution for A_2	100
48.	Plot of bed sample weight distribution for A_{29}	101
49.	Plot of sieve size distribution of Water Resources' "surface samples"	102
50.	Plot of sieve size distribution of Water Resources' "total samples"	103
51.	Plot of sieve size distribution of Water Resources' "subsurface samples"	104

LIST OF FIGURES - cont'd.

		Page
52.	Plot of sieve size distribution of "surface samples" (excluding stones below ½" sieve size) by number	105
53.	Plot of sieve size distribution of "surface samples" (excluding stones below ½" sieve size) by weight	106
54.a	Plot of sieve size distribution of "total samples" (excluding stones below ½" sieve size) by number	107
54.b	Plot of sieve size distribution of "total samples" (excluding stones below ½" sieve size) by weight	108
55.	Plot of sieve size distribution of average "surface sample"	109
56.	Plot of sieve size distribution of average "total sample"	110
57.	Plot of sieve size distribution of average "subsurface sample"	111
58.	Plot of cross-section A_1	112
59.	Plot of A_2	113
60.	Plot of A_3	114
61.	Plot of A_4	115
62.	Plot of A_5	116
63.	Plot of A_6	117
64.	Plot of A_8	118
65.	Plot of A_9	119
66.	Plot of A_{10}	120
67.	Plot of A_{11}	121
68.	Plot of A_{12}	122
69.	Plot of A_{14}	123
70.	Plot of A_{15}	124
71.	Plot of A_{17}	125
72.	Plot of A_{18}	126
73.	Plot of A_{19}	127
74.	Plot of A_{20}	128
75.	Plot of A_{21}	129

LIST OF FIGURES - cont'd.

		Page
76.	Plot of A_{22}	130
77.	Plot of A_{23}	131
78.	Plot of A_{24}	132
79.	Plot of A_{27}	133
80.	Plot of A_{28}	134
81.	Plot of A_{29}	135
82.	Plot of A_{30}	136
83.	Plot of A_{31}	137
84.	Plot of A_{32}	138
85.	Plot of A_{33}	139
86.	Plot of A_{34}	140
87.	Plot of A_{35}	141
88.	Plot of A_{36}	142
89.	Plot of A_{37}	143
90.	Plot of yearly peak discharge hydrograph for Red Deer River at Red Deer	144
91.	Mean daily discharge hydrograph for the year 1915	145
92.	Mean daily discharge hydrograph for the year 1957	146
93.	Mean daily gauge height hydrograph for the month of August, 1961	147
94.	Mean daily gauge height hydrograph for the month of September, 1961	148
95.	Mean daily discharge hydrograph for the month of August, 1961	149
96.	Mean daily discharge hydrograph for the month of September, 1961	150
97.	Plot of water surface profile between slope stations Nos. 83 and 77	151
98.	Plot of water surface profile between 77 and 72	152
99.	Plot of water surface profile between 72 and 69	153
100.	Plot of water surface profile between 69 and 67	154
101.	Plot of water surface profile between 67 and 65	155
102.	Plot of water surface profile between 65 and 63	156

LIST OF FIGURES - cont'd.

		Page
103.	Plot of water surface profile between 63 and 56	157
104.	Plot of water surface profile between 56 and 55	158
105.	Plot of water surface profile between 55 and 54	159
106.	Plot of water surface profile between 54 and 53	160
107.	Plot of water surface profile between 53 and 49	161
108.	Plot of water surface profile between 49 and 46	162
109.	Plot of water surface profile between 46 and 42	163
110.	Plot of water surface profile between 42 and 37	164
111.	Plot of water surface profile between 37 and 33	165
112.	Plot of water surface profile between 33 and 28	166
113.	Plot of water surface profile between 28 and 24	167
114.	Plot of water surface profile between 24 and 21	168
115.	Plot of water surface profile between 21 and 17	169
116.	Plot of water surface profile between 17 and 14	170
117.	Plot of water surface profile between 14 and 12	171
118.	Plot of water surface profile between 12 and 9	172
119.	Plot of water surface profile between 9 and 3	173
120.	Plot of water surface profile between 3 and 2	174
121.	Plot of water surface profile between 2 and 1	175
122.	Plot of zero bed factor against discharge (1.7 mm. gravel)	176
123.	Plot of zero bed factor against depth of flow (1.7 mm. gravel)	177
124.	Plot of V^2/gd against D/d	178
125.	Plot of F_{bo} against $g\left(\frac{\rho_s - \rho_f}{\rho_f}\right)\left(\frac{D}{d}\right)$	179
126.	Photograph of bed-load sample of cross-section A_2	180
127.	Photograph of bed-load sample of A_3	180
128.	Photograph of bed-load sample of A_5	181
129.	Photograph of bed-load sample of A_8	181
130.	Photograph of bed-load sample of A_9	182

LIST OF FIGURES - cont'd.

		Page
131.	Photograph of exposed bed between A_3 and A_4	182
132.	Photograph of left hand banks near A_2	183
133.	Photograph of the bridge pier near A_2	183
134.	Photograph of left hand banks near A_7	184
135.	Photograph of left hand banks between A_8 and A_9	184
136.	Photograph of exposed bed material downstream of Red Deer highway bridge	185
137.	Photograph of Red Deer highway bridge	185
138.	Photograph of left hand banks near A_8	186
139.	Photograph of highway and railway bridges at Red Deer	186
140.	Photograph of general view near A_{16}	187
141.	Photograph of right hand banks near A_{17}	187
142.	Photograph of right hand banks near A_{18}	188
143.	Photograph of right hand banks near A_{24}	188
144.	Photograph of general view of the river near A_{13}	189
145.	Photograph of exposed bed material near A_{14}	189
146.	Photograph of exposed bed material upstream of A_{24}	190
147.	Photograph of the flume	191
148.	Photograph of the flume	191
149.	Photograph of the inside of the flume	192

CHAPTER I

INTRODUCTION

1.1. In 1961 the Alberta Government Water Resources Department undertook a geomorphic survey programme on which the author was employed. Their objects were (i) to obtain quantitative information that could be used to answer engineering problems related to interference with channel regime, e.g., building a dam, and (ii) to test regime relations believed to have special dynamical significance. In selecting a river on which to begin these studies, the Department looked for one on which, over its length within the boundaries of the province, could be found:-

1. Varying degrees of slope
2. Varying size and quantity of bed-load
3. Reaches of relatively meandering channel and reaches of straight channel
4. Accurate discharge and gauge readings over an extended period of years.

Of the rivers that qualified in this respect, the Red Deer River was chosen since in addition, it is possible that in the future artificial control may be established in its headwaters. Under such conditions, it would be essential to know the character of this river in terms of regime theory in order to predict the effect such controls may or may not have on the regime of the river. The first site chosen for the initial investigations was in the vicinity of the City of Red Deer, consisting of a reach 24.5 miles long, extending from 9.1 miles upstream of the Red Deer railway bridge to a point 15.4 miles downstream of it. This reach was chosen because:-

1. It meanders without appreciable braiding (Figs. 1 to 4)
2. It is fairly well incised

3. It has gravel of about 2" median size on the bed and generally this size and finer* can be found on the sides.

4. The gauge site is located at the City of Red Deer highway bridge for which discharges and gauge readings have been recorded from January, 1912. The data for the gauging station are as follows:-

   (i) The catchment area is 4420 square miles.

   (ii) The highest gauge of 17.3 ft. was recorded on January 27, 1915.

   (iii) The highest corresponding average daily discharge was 56000** cfs.

   (iv) The lowest gauge of 3.0 ft. was recorded in December 1922.

   (v) The lowest corresponding discharge was 64** cfs.

   (vi) The median annual peak flood is 13,000** cfs. (Fig.5).

   (vii) The 100 year flood is 80,000** cfs. (Fig.5).

   (viii) Ratio of 100 year flood to median flood is 6.15.

   (ix) Suspended load is of very small quantity.

1.2. The basis of quantitative analysis in this thesis is regime theory (Ref. 1) where applicable. Its equations apply accurately to controlled canals carrying sand and are believed to apply, <u>in functional</u> form, to meandering streams if used for average and for some special dimensions, but the coefficients to apply to the equations cannot be specified simply at present. A somewhat similar state of affairs arises in attempting to specify Manning's n for a pipe; a person of experience can specify from visual inspection but cannot reduce his experience to a set of rules that can be used by others.

---

* Finer than about 0.1 inches.

** Average daily discharge, and not instantaneous value.

1.3. A major omission from practical regime formulas (as distinct from basic ones) is the coefficient in the relation of zero bed factor to gravel size by the formula $F_{bo} = \sqrt[3]{\lambda D_{mi}}$, which is admitted to be crude and possibly functionally wrong. The reason for the omission is that the "size" of gravel is determined subjectively at present because there is no basis for a definite rule to specify what is the mean size of a material that is graded in an apparently unsystematic manner. Accordingly one principal aim of the author was to seek some rational system in the constitution of the part of a gravel that moves as bed-load during flood; if a system could be discovered then the definition of a consistent measure of bed-load would become possible. This portion of the investigation has proved satisfactory.

1.4. Another principal aim was to test whether the regime slope formula, with a zero bed factor of the order guessed by Dr. Blench and with the crude meander correction coefficient of Ref. 1, Sec. 6.2.1., would apply approximately to the behaviour of steep sections of river during low flow that seemed sufficient to just move, or to be close to moving, the bed. If it did then the examination of other rivers at low flow would be justified. The practical importance of this is that, at present, it is usually considered that river regime should be analysed at high discharge to ensure that the bed is moving, since without movement regime equations do not apply. The infrequency and short duration of high flows, and the difficulty of measuring during floods, are serious handicaps to rapid accumulation of reliable data. But, if even a few rapids during low flow are analyseable, fairly exact data may become obtainable in considerable quantity during a short time.

1.5. The whole thesis discusses how the three aims described above were achieved and is intended to be essentially quantitative.

1.6. It is appropriate at this stage to define certain expressions and terms used in the body of the text as follows. Standard symbolism is in Appendix A.

Length Axis. An axis parallel to a line connecting the most distant points in the stone.

Breadth Axis. An axis parallel to the longest line within the stone which is perpendicular to the length axis. The length of this longest line is the "breadth".

Thickness (Triaxial) Axis. An axis perpendicular to both the length and breadth axes. (The word "triaxial" appears in American literature.)

Thickness. The greatest dimension parallel to the thickness axis. Ref. 2, p. 117 gives more detail about the measurements of the stones.

Shape factor. The ratio of the thickness to the square root of the product of length and breadth.

Bed factor. The ratio of the square of mean velocity to mean depth, $\frac{V^2}{d}$, denoted by F_b.

Bed factor zero. Bed factor when bed load charge is vanishingly small. This is termed "bed factor at vanishingly small charge" or "zero bed factor".

Bed-load. Solids moving along the bed by sliding, rolling, saltating or a combination of these actions.

Boulders. Stones of thickness greater than 60 mm.

Charge. The ratio of the weight (in air) of bed load per unit time to weight of water per unit time. It is measured in thousandths of 1 percent by weight.

Dunes. Bed waves which move in the direction of flow.

Equivalent diameter. The diameter of the spherical stone of the same density and weight.

Meander. A river length of two consecutive loops, one flowing clockwise, the other anti-clockwise.

Meander breadth. The distance between lines drawn tangental to the extreme limits of successive fully developed meanders.

Meander length. The direct distance between corresponding points of a fully developed meander.

In regime. The state when, on long term, a channel does not change its average behaviour.

Saltation. Bed movement by hops or by leaping.

Sheet flow. Bed-load movement without dunes or anti-dunes.

CHAPTER II

THE SIZE DISTRIBUTION OF RIVER BED GRAVEL

2.1. Introduction. According to Ref. 3 the distribution of sizes within river bed samples of sand follows a definite law. In fact, petrographers have adopted logarithmic probability paper for plotting the "percentage coarser than" curves that engineers plot to ordinary or semi-log scale when analysing soils and aggregates. Their reason is that the plotted points, on this kind of paper, fall on approximately straight lines; and the implication is that the logarithm of particle size is distributed approximately according to the "normal law of error". In the "normal law of error" the measurements of quantities are found to be distributed about their means in a special symmetrical pattern, so that the frequency of occurrence of measures, in a range of dx, that deviate by an amount x from the mean is proportional to e^{-x^2}. dx. The plot of relative sand size against "percentage by volume coarser than" from the Strait of Georgia up the Fraser River (Fig. 6) indicates remarkable agreement with the logarithmic normal distribution. Erb (Ref. 4) found that the dispersion for sand samples increased slightly with median diameter, but his data included materials that seemed of mixed origin so the dispersion should be expected to be greater than in natural river bed materials.

Because of this standard distribution, it is practical and logical to specify a sand, for regime purposes, by its median diameter without any reference to distribution of sizes. On the other hand very little analysis has been done of gravel rivers and general belief seems to be that the distribution is not systematic. However, gravel dug from shoals is likely to have its pores full of fines, whereas gravel moving on a river bed during flood lacks the fines as they have gone into suspension. There seems some possibility, therefore, that gravel that partakes of bed movement may show some system.

To test for a system one has to overcome the practical difficulty of analysing samples. Using large samples obtained by draglines, etc. is obviously very expensive. Wolman (Ref. 5) devised a common sense field method by which an unaided observer could obtain reasonable samples. It consists of the determination of grain size based upon an analysis of the relative area covered by grain sizes.

Wolman's method focusses attention on the different ways of specifying "frequency". Soils engineers usually weigh the material on their sieves and, therefore, measure the weights of materials between certain sizes. A person collecting large stones by hand would prefer to state the number of stones between different standard sizes. The median size by the former system would be the size of stone that had half the weight of all stones on one side of it (and, of course, half on the other) whereas the median by the second system would be the size that had half the number of stones to one side of it.

2.2. Wolman's method for sampling coarse river-bed material: Ref. 5. The method is quoted as below:-

"(a) In the desired reach of the stream a grid system is established either by pacing or with actual lines. The size of the grid is determined by the length of reach which the sampler desires to describe. This may include both a riffle and a pool, a riffle alone, or a pool alone. If comparisons are to be made between reaches, the sampler must obviously be consistent in his choice of the length of reach to be included in the sample.

(b) After establishing the grid, which can be done by a pacing traverse as the sampler picks up each pebble, 100 individual pebbles were picked up from the bed. (The sampling is probably less subjective when lines or tapes rather than pacing are used to fix the individual sampling points.) Randomness in the selection of each pebble can only be obtained if the sampler tries not to look at the bed as he picks up each pebble. His practice is to draw each pebble from beneath the tip of the toe of his boot.

(c) The intermediate axis* of each pebble is measured.

(d) Unless the actual diameters are of interest, a rule or scale can be designed showing class limits only and each pebble tallied within grade class immediately. For this purpose the Wentworth scale is probably the most useful.

(e) With the pebbles placed in the proper classes, it is a simple matter to plot a frequency distribution of the sample. This plot is further simplified if the Wentworth size classes are denoted by the Θ notation (Krumbein, 1936)** in which $\Theta = -\log_2$ diameter in mm. Using this logarithmic scale the frequency distribution can be plotted on arithmetic coordinate paper (Fig. 7).

2.3. Method of sampling Red Deer River bed gravel. The following method was used by the writer for obtaining samples at the cross-section desired to be investigated. It is essentially the same as Wolman's method quoted above, and is detailed as follows:

(a) A line perpendicular to the direction of flow was established visually.

(b) By wading out from the river's edge stones were collected by hand commencing at the river's edge and at intervals of two paces until the water became waist high precluding further sampling.

(c) At each of the sampling points a stone was picked where the toe of the boot touched the stone. Fine material of about 0.1 inches was neglected and underneath the fine material, a handful of the river bed material was scooped up. The collected material was brought back to the shore.

(d) Step (b) and (c) were repeated with the initial sampling point midway

---

* For intermediate axis, the term "breadth" has been used in the body of the text.

** Reference 6.

between the first two points and two pace intervals thereafter until the water depth again precluded further sampling. Therefore, in effect, samples were collected at intervals of one pace along a line from the shore to a point in the channel where the water was waist deep.

2.4. Limitations of the sampling method. The principal limitation encountered was the inability to measure fine stones (stones less than about 0.1 inches size). The difficulty of sampling in deep water is a second limitation; the river was waded up to a depth of about $3\frac{1}{2}$ ft. Velocity more than 3 ft. per second is a third limitation in this practical method of sampling. The last two limitations handicap obtaining the sample throughout the width of the river; however it was assumed that the sample obtained by wading the river until water became waist high would be a representative sample.

2.5. Precautions taken while sampling. The main precaution taken was not to look at the stone, while picking it from the bed of the river.

2.6. Measurements of the stone size: The sizes of stones were measured in terms of length, breadth and thickness as defined in Sec. 1.6. See Tables 1 to 4. A sketch for the size of stone is given below:-

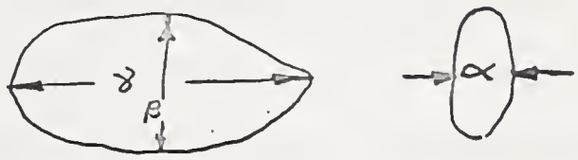


Fig. 8 (Sketch showing length γ, breadth β and thickness α.)

2.7. Formula for equivalent spherical diameter: In 1949, A. T. Corey, (Ref. 7) working with individual sand particles suggested a simplified shape parameter which he called the shape factor s.f.:

$$s.f = \frac{\alpha}{\sqrt{\beta\gamma}}$$

In Ref. 2, p. 117, shape factor is defined as the ratio of rounded actual volume to hypothetical maximum prism. The writer assumed that the shape factor of a stone is approximately the same as that of a sand particle and

therefore

$$\text{Volume of the stone} = S.F \times \alpha\beta\gamma$$

$$= \frac{\alpha}{\sqrt{\beta\gamma}} \times \alpha\beta\gamma$$

$$= \alpha^2 \beta^{\frac{1}{2}} \gamma^{\frac{1}{2}} \qquad (A)$$

Volume of equivalent sphere size stone

$$= \frac{\pi}{6} \times \phi^3 \qquad (B)$$

Equalizing (A) and (B),

$$\phi = 1.24 \alpha^{\frac{2}{3}} \beta^{\frac{1}{6}} \gamma^{\frac{1}{6}} \qquad (C)$$

The formula (C) was verified to some extent by the Water Resources engineers by weighing some specimen of stones. It is not mathematically derived and should not be used without experimental verification.

2.8. Relation between equivalent spherical diameter and thickness: The sizes of stones of sample No. 2, 3, 4, and 5 were expressed in terms of ϕ and an attempt was made to find an empirical relation between ϕ and α and therefore ϕ and α were plotted on log-log paper. The writer obtained the relations by drawing the best fit lines of 1:1 slope by eye, which were tested by four individual persons. The best fit lines drawn by the author were the same as those drawn by others in some cases, whereas in other cases they differed by 2% to 5%. The results obtained are enlisted below:-

(a) Fig. 9 for sample No. 2 shows $\phi = 1.58\,\alpha$

(b) Fig. 10 for sample No. 3 shows $\phi = 1.6\,\alpha$

(c) Fig. 11 for sample No. 4 shows $\phi = 1.5\,\alpha$

(d) Fig. 12 for sample No. 5 shows $\phi = 1.5\,\alpha$

(e) Fig. 13 for all the above 4 samples shows $\phi = 1.55\,\alpha$

2.9. Description and frequency analysis of samples: Samples collected were found to be a mixture of smooth, rounded, angular, flat and subangular

(Photos. Figs. 126 to 130). The procedure of analysis is as follows:-

(a) Plotting by number: Sizes of stones against percentage by number equalled or exceeded were plotted on logarithmic probability paper.

(b) Plotting by weight: Stones were measured in terms of length, breadth and thickness, because of inconvenience of weighing stones at site. Weight of a stone was assumed to be proportional to the cube of its thickness since Φ varies as $\propto$. Assuming density of each stone to be the same, size of stones against percentage by weight equalled or exceeded were plotted on log-probability paper. Table 5 shows a sample calculation. It is suggested for future investigations that a spring balance should be carried.

(c) Plotting of size distribution of an average sample: The plottings of size distributions of all the samples as in (a) and (b) were made on log-probability papers and it was assumed that the best fitting lines, considered together, would represent the size distribution of an average sample for the whole reach of the river. (Figs. 42 to 45)

(d) Best fit lines: Best fit lines were drawn by eye and were tested by four persons. In general the lines drawn by the author were coincident with those by the different persons, but in a few cases they varied to a large extent, depending on individual judgment. However, the median size was not affected at all.

2.10. Details of stone samples: The details of sample No. 1 are:

(i) The sample was picked from cross section A_2 site and consisted of 116 smooth, angular, flat and rounded stones. The maximum and minimum thicknesses were 7.2 and 0.36 inches respectively. Fig. 126 shows the sample as collected at the right hand bank of the river.

(ii) Fig. 14 shows the plotting of thickness by number on logarithmic probability paper, which indicates a log normal distribution with median thickness of 1.3 inches. The range of sizes from 1% to 99% is 20 times.

(iii) Fig. 15 shows the plotting of thickness by weight and indicates log normal distribution with median thickness of 4 times.

(iv) Fig. 15 shows the nondimensional plot of α/α_{50} by weight.

For the description of rest of the samples see Table 6 (Figs. [illegible] to 45).

2.11. Relation between median thickness of a stone in a sample by number and that by weight: The plottings of the thickness by number and that by weight of samples 6, 7, 8, 9, 10, 11, 13, 14 and 15 show an approximate relation of $m\alpha_w = 1.8\, m\alpha_n$, where $m\alpha_w$ and $m\alpha_n$ are median thickness by weight and number respectively. See Fig. 46.

2.12. Determination of median equivalent spherical diameter from the actual weights of the stones: Stones of sample 1 and 13 were weighed. Fig. 47 and 48 show the plottings of percentage by number, the weight of each stone equalled or exceeded against the weight of each stone, and indicate approximate log-normal distributions.

From Fig. 47 median weight = 4.8 ounces. Assuming density of stone equal to 144 lbs./cft., ϕ comes to 1.9 inches.

The above method gives results close to those obtained from the ϕ's calculated from α, β and γ.

2.13. Description of the bed load material sampling with sieves by Water Resources engineers: An attempt was made by Water Resources engineers to set up a simple method of measuring river bed material size based upon the grain size curves obtained from standard sieve analysis.

The peculiarity of this method was the inclusion of fine grains, which would be drifted away while shovelling under water. Therefore their main problem was the selection of the bed material to be analysed, because the Red Deer river flowed at a considerable depth all season. The accessible areas were those exposed gravel banks along the river edge or on bars in the central portion of the river. They had no way of knowing whether bed material under the flowing water was, in fact, similar to that exposed, but they hoped that a sufficient number of samples would indicate average conditions.

2.13.1 Detailed procedure: The detailed procedure was as follows:-

(i) A three foot square wooden frame was laid down on the area of exposed

gravel selected.

(ii) Each rock, pebble or sand grain (insofar as possible) within this square yard that was exposed to the surface was carefully picked up and gathered into one sample (surface sample).

(iii) Everything that remained after action (ii) within this same square area to the depth of the deepest lying surface stone (removed in operation (ii)) was then shovelled into a second container. This was called the subsurface sample.

(iv) A sieve analysis (by weight and number) was done for both the surface sample and the subsurface sample.

(v) The results were presented for:

(a) The surface sample

(b) The subsurface sample

(c) The total sample (a combination of (a) and (b)).

It was felt that only (a) and (c) and not the subsurface sample would be useful.

2.14. Analysis of samples by sieves: Analysis of samples was done as below:-

(i) Sieve sizes for surface, total and subsurface* samples were plotted against percentage retained by weight on logarithmic probability paper. (Figs. 49 to 51).

(ii) Sieve sizes for surface and total samples (excluding the stones below sieve size of ½") were plotted by number and weight on logarithmic probability paper. (Figs. 52 to 54b).

(iii) Figs. 55 to 57 show the "composite samples" of Figs. 49 to 51. That is, it is correlated to indicate the analysis of the sample obtained by mixing the individual ones.

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* Subsurface sample is included in the total sample

The results of (ii) and (iii) are tabulated in Table No. 7

2.15. Definition of median diameter of active gravel bed for regime calculations. It appears that the gravel observed has a median spherical diameter (by weight) of about 3.4 inches (86.4 mm) with a size range of about ten times between 1% and 99% frequency. Also, active river-bed sand of about 0.3 mm median spherical diameter by weight has a corresponding range of about 4 times. If we assume that the range, n times, varies according to a power law with the median size, we have the relation:

$$(86.4 \text{ mm}/0.3 \text{ mm})^{x} = 10/4$$

which gives x very close to 1/6. Practically, therefore, one might adopt the tentative rule that the top range of effective sizes in a river-bed gravel varies as the sixth root of the median effective size. With this rule available one might find the "effective size" of a gravel as follows:- (1) Express the estimated median spherical diameter by weight in millimeters and obtain the sixth root of the ratio of this size to 0.3 mm. Accept four times this figure as n, the effective range of gravel size. (2) Decide (necessarily somewhat subjectively) the top size of gravel that rolls along the bed in high flood. (3) Reject, from gravel samples, all material smaller than one n-th the top size. (4) Accept the median of the residue as the effective gravel size for regime calculations. (5) Check whether this size agrees reasonably with what was estimated in (1) and repeat the process, using the result of (4), if it does not.

CHAPTER III

REGIME SLOPE ANALYSIS

3.1. Introduction: There are serious difficulties in applying regime formulas, and they are discussed in some detail in Ref. 1, Sec. 5.18. However, the basic regime formulas for negligible bed-load charge are believed to be dynamically significant and exactly applicable when all the following conditions hold.

(i) A stream or canal is straight.

(ii) Sides behave as if hydraulically "smooth". Technically this means that roughness constant of the sides depends on the nature of water-sediment complex.

(iii) Bed width exceeds three times the depth.

(iv) Sides stand at slopes approximating those found for cohesive sides in nature.

(v) Discharges are steady.

(vi) Sediment load, however complex, is steady.

(vii) A non-cohesive load, however small, moves along the bed in dune formation.

(viii) Speed is less than critical, i.e., less than the speed of small gravity waves.

(ix) Sediment size is small compared with the depth of flow.

(x) Width, depth and slope have adjusted to final (or regime) values.

It is believed further, Ref. 1, that the functional forms of the regime equations can be used for appreciable charge and for fluctuating discharges and charges in the presence of meandering, by applying coefficients. Because of the tremendous variability of practical conditions, normal application is confined to average conditions or to very special ones, and, even then, estimates of what coefficients to apply have to be rough and are based on crude observations of actual occurrences in a relatively few cases. There is a

further difficulty, as Bhattacharya has shown (Ref. 8), and the author verified to some extent in the Hydraulics Laboratory, University of Alberta, that, when stone size relative to depth exceeds a certain limit for a given discharge intensity then the estimates of bed factor by the standard rough formulas in terms of sediment size alone are obviously wrong; so the application to gravel rivers should not be made at too low discharge intensities. Finally, there is a major difficulty that, in dealing with the slope fomula which is the most likely to yield results, the effect of stone size and of meandering have to be decided together, yet neither is directly measurable. In the absence of special observations on straight reaches, the author was compelled, therefore, to analyse by finding whether the values of the one factor within what was believed to be a practically justifiable range were consistent with values of the other believed to be practically valid.

3.2. Programme for collection of data: Aerial photographs 1" = 600' and 1" = 3333' and maps, 1" = 1 mile, obtained from the Department of Lands and Forests, Figs. 1 to 4 (aerial photographs 1" = 3333'), show the river chosen for study. It was decided to study 24.5 miles of the river, 9.1 miles upstream of the Red Deer railway bridge and 15.4 miles downstream of it, because of (i) accessibility of the river; (ii) its fairly sinusoidal meandering behaviour; (iii) no intaking of any tributary excepting one (Blindman River), which is very small, and (iv) gravel bed. Water Resources Department decided to collect the following data:

(i) Bed-load samples (see Chapter II)

(ii) Cross-sections

(iii) Discharge measurements

(iv) Photos

(v) Profile of the river

(vi) Suspended load samples.

3.3. Collection of Data: Survey work was done by a survey crew of the Department of Water Resources during the period August 7 to September 13, 1961. The first week was spent in establishing the bench marks on the river and referencing them to geodetic bench marks. The collection of data started on August 15 and ended on September 13, 1961, during which time the gauge heights and discharges at Red Deer gauging station fluctuated from 4.01 ft. to 5.67 ft. and 789* cfs. to 2820* cfs. respectively. Survey headquarters remained at Red Deer during the whole period of collection of data.

3.3.1. Cross-section: The number of cross-sections of the river was 37, mostly at the nodes and antinodes of complete meander bends, Figs. 1 to 4 show the locations of the cross-sections labelled with an A. Water levels were mostly taken on both the shores of the river. Bed levels were generally taken at every 10 ft. The maximum and minimum water surface breadths and mean depths were 521 ft. to 169 ft. and 4.30 ft. to 0.826 ft. respectively. Most of the cross-sections were nontrapezoidal. Figs. from 58 to 89 show the cross-sections.

3.3.2. Discharge measurements: Discharges were taken from the records of Dominion Water Resources Bureau for Red Deer River gauging station. It was assumed that the discharge was not affected by inflow or outflow and remained the same, as at Red Deer throughout the reach of the river, chosen for study. The discharge fluctuated from 789* to 2820* cfs. during the whole period of collection of data. The Red Deer River gauging station at Red Deer has official number $5CC_2$ and is located Sec. 36, Tp. 31, Rge. 7, W 5th Mer., Alberta, at the highway No. 2 bridge in the City of Red Deer. Drainage area for the station is 4420 sq. miles. A wire weight gauge has been used for recording gauge height from 1912 to date. Average discharge for 43 years (up to 1960) of record is 1851 cfs. Daily maximum discharge, recorded on

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* Average daily discharge and not instantaneous value.

June 27, 1915 (g.h. 17.30) was 56000 cfs. Daily minimum discharge, recorded on December 7, 1922 (g.h. 3.00) was 64 cfs. Instantaneous maximum discharge recorded at 9:20 p.m. on June 27, 1915 (g.h. 19.05) was 68,250 cfs. Fig. 90 shows the yearly peak discharge hydrograph for the gauging station. Figs. 91 and 92 show the mean daily discharge hydrograph for the years 1915 and 1957. Figs. 93 and 94 show the mean daily gauge height hydrographs for August and September 1961. Figs. 95 and 96 show the mean daily discharge hydrographs for August and September 1961. Fig. 5 shows the maximum annual peak flood frequency diagram with a median flood of 13,000 cfs. and a 100 year flood (extrapolated) of 80,000 cfs, ratio = 6.15.

3.3.3. Photographs: 173 photographs were taken of bridges, banks, bed-load samples collected on banks, exposed bed due to receding of water, and general views of the river to show banks and vegetation. Figs. from 126 to 146 are selections.

3.3.4. Profile: For the profile of the river, water levels were taken on one side, or on both the sides of the river, depending on the radius of curvature of bend. To obtain an adequate profile of water surface 83 main slope stations were fixed for the whole reach. Figs. 1 to 4 show the slope stations in addition to the A series. Strength of the crew averaged 15. It took two days (August 22 and 24) with six shifts to mark the instantaneous water levels by reaches. In one reach water level marks would be made simultaneously at different sections; the levels of the marks would be observed later. Distance from station to station was measured with roller tape in feet on the easily accessible side of the river. By noting the rise or fall of water level from shift to shift, instantaneous water levels were obtained for the whole reach. Distance was corrected by -2%, which was verified by chaining a certain distance and roller taping the same. Figs. 97 to 121 show the instantaneous water surface profile. Gauge heights at the Red Deer River gauging station during the operation of marking water levels, i.e., on

August 22 and 24 were not available in records. The gauge height on August 25th was 4.74 ft.

3.3.5. Suspended load sampling: Initially, it was proposed to obtain suspended load samples from all cross-sections, but during the period of collection of data, the river was at low stage and obviously did not contain enough suspended load to merit measurement.

3.4. Summary of the regime slope formulas: The forms of the regime slope equation (Ref. 1), as applied to ideal canals, or non-meandering rivers of large bed load charge are below, for ready reference;-

$$S = \frac{F_{bo}^{5/6} F_s^{\frac{1}{12}}}{K Q^{1/6}} f'(C) \qquad (A)$$

in which $f'(C) = (1 + 0.12\,C)^{5/6} / (1 + \frac{C}{233})$

and $K = 3.63\,g / g^{1/4}$

$$S = \frac{F_{bo}^{\frac{7}{8}}}{K b^{1/4} d^{1/8}} f''(C) \qquad (B)$$

in which $f''(C) = (1 + 0.12\,C)^{7/8} / (1 + \frac{C}{233})$

$$S = \frac{F_{bo}^{11/12}}{K b^{1/6} Q^{1/12}} f'''(C) \qquad (C)$$

in which $f'''(C) = (1 + 0.12\,C)^{11/12} / (1 + \frac{C}{233})$

All notations are given in Appendix A.

3.5. Use of slope formulas for a river: In deciding which of the preceding formulas to use, and with what coefficients or values of parameters, the following points had to be considered:-

i The stage of river at which the bed load just kept moving was unknown and was unlikely to be that at which it would just start to move. However, air photos in general indicate that steep reaches of rivers during low supply can have moving beds. So it seemed likely that the steepest

reaches of the Red Deer River might be moving, or might have been moving had they not stopped at slightly lower discharges. It would be reasonable, therefore, to assume, tentatively, that the formulas might give fair results if applied to steep reaches only, with C practically zero, i.e., with $f(C) = 1.0$.

ii. The conventional way to use slope formulas is with a rather vague "meander slope coefficient", k, which multiplied by S from the slope formula is supposed to give about the S found in a meandering channel in practice. Values from 2.0 to 3.0 seem possible according to literature, and choice can be made only in terms of experience. Also, every slope formula form needs a value of F_{bo} and this, too, is determined subjectively, like Manning's n. For the present analysis one could either assume an F_{bo} and find, from data, whether k looked reasonable, or vice versa. Dr. Blench suggested starting from F_{bo} lying between 4 and 6 since he preferred to estimate F_{bo} rather than k.

iii. Obviously there is some definite Q at which bed movement continues with vanishingly small C in a straight channel. As there is no way to determine its value, the best approach is to use a formula with a small index of Q. So it appears that equation (C) has merit in the present problem. Actually, in a meandering channel, reduction of discharge cannot cause a gradual reduction and then cessation of bed movement, as might be expected in a straight one, since the meandering channel has rapids and pools at low discharge, so there can be appreciable bed movement in parts and no bed movement in other parts.

iv. With sections quite non-trapezoidal a formula containing b and d is of little value.

v. At low flow the sides cannot be near the state of erosion so F_s is not applicable. This rules out the use of equation (A).

Taking all these points together the reasonable course seems to be to apply equation (C), with C = 0 and F_{bo} = different values within the range

suggested by Dr. Blench. Insertion of actual data in this formula would give values of k that could be compared with what are supposed to be limiting values. A value less than 2.0 or > 3.0 would be suspected; a value less than 1.0 would be impossible and value close to 1.0 highly improbable. It is worth noting that the main practical justification for using a regime formula at all is that Q appears to the 1/12th power so a large error in Q would be unimportant.

3.6. Procedure for determination of meander coefficients: Due to the lack of proper and sufficient data for direct regime slope analysis, Dr. Blench, in view of his experience, based on relative judgment from different rivers having different sizes of bed-load material suggested that zero bed factor for Red Deer River is likely between 4 and 6. Therefore the following method, which is the basis of analysis, was used:-

(i) For the determination of energy slope for a particular section line, the nearest water surface slope stations upstream and downstream of the section were taken into consideration if the total reach was of fairly uniform slope. The slope was calculated by dividing the instantaneous water level drop between the stations by the distance between them measured along the deep water channel. It should be noted that the central distance was not used, but the one that was obtained by roller taping on the accessible edges of the river, because it was observed there was little difference between them. Velocity head correction factor was neglected because it was very small and the data as a whole were under consideration.

(ii) Steep reaches defined by slope greater than 1/1000* were chosen for study. 18 such sections were found. The slopes of the first and the last cross-section were not calculated, because the water levels

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* Some of the reaches have slopes a little less than 1/1000.

upstream and downstream of the sections respectively were not obtained.

(iii) In the formula:-

$$S = \frac{k F_{bo}^{11/2}}{K b^{1/6} Q^{1/2}} f'''(c) \qquad (D)$$

C was equal to zero, K was taken as 1800 for cold water and b was taken as a surface breadth. Note that $b^{1/6}$ is insensitive to moderate error in b.

(iv) Assuming F_{bo} = either 4, 5 or 6 and inserting data, k was found, see Table 8.

3.7. Sample calculation of k: A sample calculation for cross-section A_{17} is given below:-

See Figs. 3, 71 and 110 for plan, cross-section and profile.

Water surface elevation at slope station 42	= 2766.55 ft.
Water surface elevation at slope station 41	= 2762.70 ft.
Distance of 42, from zero position (A_1 position)	= 69200 ft.
Distance of 41, from zero position (A_1 position)	= 66100 ft.

Therefore slope $\simeq \frac{1}{800}$

Discharge at Red Deer	= 942 cfs.
Discharge used in the formula	= 942 cfs.
Water surface breadth	= 230 cfs.
Breadth used in the formula	= 230 ft.

Using the slope formula for rivers (charge being negligible),

$$S = \frac{k F_{bo}^{11/2}}{1800 b^{1/6} Q^{1/2}},$$

we get $kF_{bo}^{11/2} = 9.8.$

Now, if F_{bo} = 4, then k = 2.76 ≃ 2.8;

F_{bo} = 5, then k = 2.36 ≃ 2.4;

and F_{bo} = 6, then k = 1.9.

Since the river is convoluted, k would be taken as 2.8 and the corresponding zero bed factor of 4.0.

3.8. Determination of charge at high flow: $kF_{bo}^{11/2}$ found from steep slope analysis was inserted in formula (D) to find f"'(c), assuming that, at high flow, slope is fairly uniform and all the bed is active. For the conditions of observations, the charge was found from f"'(c), to vary from 4.5 to 2.2 for annual peak flood of one to seventy%frequency. (See Table 9). The results seem fairly reasonable, in view of the fact that charge for many rivers is of the order of 1 or 2.

3.9. A sample calculation of charge: Charge for median flood was found to be 2.6. the calculation is as follows:-

Median flood for the river (see Fig. 5) is 13000 cfs.

Meander coefficient = 2.75)
) $kF_{bo}^{11/2}$ = 10.0
Zero bed factor = 4.0)

Regime breadth = 260.0 ft.

Substituting in the formula:

$$S = \frac{2k F_{bo}^{11/2}}{K b^{1/6} Q^{1/2}} f'''(c)$$

We get $(1 + 0.12C)^{11/3} + (1 + \frac{C}{233}) = 0.584 \times 13000^{1/2}$

Therefore C = 2.6.

3.10. Relation between median size of bed-load material and zero bed factor: With the means of defining a median equivalent spherical diameter available from Chapter II the following formulas based on F_{bo} = 4.0 were obtained, see Table 10.

(i) $F_{bo} = \sqrt[3]{18\,\phi_{50}}$ where ϕ_{50} = median equivalent spherical diameter by weight in inches

(ii) $F_{bo} = \sqrt[3]{34\,\phi_{50}}$ where ϕ_{50} = median equivalent spherical diameter by number in inches

(iii) $F_{bo} = \sqrt[3]{22\,\alpha_{50}}$ where α_{50} = median thickness by weight in inches

(iv) $F_{bo} = \sqrt[3]{47\,\alpha_{50}}$ where α_{50} = median thickness by number in inches.

For other values of F_{bo} the coefficients will be different.

For F_{bo} = 5, 18, 34, 22 and 47 become 35, 66, 45 and 92 respectively.

CHAPTER IV

AUXILIARY FLUME EXPERIMENTS

4.1. Introduction: (Ref. 8) Bhattacharya in flume experiments with 1.7 mm. gravel (which may represent gravel of quite a large diameter in a prototype) with and without charge, size of flume being 18' x 1' x 2.5' deep, has shown that (i) at sufficiently small charge and small discharge, 1.7 mm. median diameter gravel does not form dunes, but it forms dunes as the charge or discharge is increased; (ii) after the formation of dunes, the bed characteristics follow the same pattern as for sand; (iii) dunes which have been formed artificially on the bed of 1.7 mm. gravel are washed away if discharge is reduced sufficiently; (iv) the zero bed factor decreases as discharge increases; (v) as discharge increases the charge necessary to form dunes tended to become less and less. On the basis of Bhattacharya's experiments, the author made experiments in a large flume (120' x 3.0' x 2.5' deep) with 1.7 mm. gravel, without charge, in the Hydraulics Laboratory of the University of Alberta and verified Bhattacharya's results with the addition that F_{bo} appears to reach a minimum value for the discharge intensity of the order of 1.9 cfs./ft. when $D/d = 0.0039$. The object of repeating Bhattacharya's work was to overcome his difficulty of having too small a flume to obtain a minimum F_{bo} before entry length became comparable with flume length. Practical application was made to low discharge Red Deer River conditions.

4.2. Description of the apparatus: The apparatus, essentially Bhattacharya's to large scale consisted of the following:

(a) Adjustable glass walled flume

(b) Entrance tank to flume

(c) Orifice meter

(d) Tail gate

(e) Scales, gauges, tapes, etc.

The flume consisted of a 3.0' wide, 2.5' deep and 120' long rectangular channel with glass sides and brass bottom (Figs. 147 to 149). For detailed description of parts of the apparatus, see Ref. 8.

4.3. Procedure: The flume was filled with 1.7 mm. diameter gravel to a depth of about $3\frac{1}{2}$" and the surface of the gravel was made level. Nine runs were made with discharges from 5.52 cfs. to 1.95 cfs. with depths varying from 1.43 ft to 0.47 ft. These runs were made for sufficient time to allow them to develop a working condition; the times were between 15 hours to 72 hours. The working regime condition was supposed to have been established when the particles composing the bed were just on the point of starting or stopping and was achieved by imposing a fixed discharge and then adjusting the depth by tail gate to attain the desired condition.

4.4. Measurements recorded: (a) Depth. (b) Discharge. Results are in Table 11.

4.4.1. Measurement of depth: Depth measurements were taken from the scales erected on the two sides of the flume. In certain cases the measurements at the centre were made as well as at the sides, using a point gauge and the mean was found.

4.4.2. Discharge: The discharge was measured by means of an orifice meter in the supply pipe and was checked by a current meter in the flume. The readings of the meter were close to those of the current meter.

4.5. Observations: The following runs were made for different runs:

(i) Run No. 1. Discharge was fixed at 4.4 cfs. Depth was varied from 1.10 to 1.15 ft. Zero bed factor conditions were observed at 1.13 mean depth of flow, when mean velocity and bed factor were 1.34 f.p.s. and 1.59 respectively.

For rest of the runs, see Tables 11 and 12.

4.6 Analysis of experimental results: The writer repeated, with larger apparatus, Bhattacharya's experiments for C-Q and found that F_{bo} decreases toward what we may expect from the rough Lacey rule as discharge

increases.

From Fig. 122 it is seen that at a discharge of 5.52 cfs. the zero bed factor = 1.22 while for a discharge of 1.95 cfs. it is 4.28. Fig. 123 shows the plot of F_{bo} against d.

The following interesting equations are obtained from Ref. 1, Sec. 5.18.

$$\frac{V^2}{gd} = f_n\left(\frac{VD}{\vartheta}, C, \frac{b}{d}, \sqrt[3]{g\vartheta}\,\frac{D}{\vartheta}\right) \qquad (1)$$

$$\frac{V^2}{gd} = f_n\left(\frac{D}{d}, C, \frac{b}{d}, \sqrt[3]{g\vartheta}\,\frac{D}{\vartheta}\right) \qquad (2)$$

Assuming $\frac{b}{d}$ unimportant, the plot of V^2 against $\frac{D}{d}$ (Figs. 124 and 125*) means that, in the appropriate range, $V \doteqdot$ constant and this seems to be indicated by Mr. C.R. Neill with his bridge pier model with 1.7 mm. gravel. It also shows that the old incorrect idea that scour occurs at a fixed velocity for a given material may be based on small scale experiments and is consistent with $F_b = f_n\left(\frac{D}{d}, \frac{D\sqrt[3]{g\vartheta}}{\vartheta}\right)$ in general.

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* shows the plot of $\frac{V^2}{d}$ against $g\left(\frac{\rho_s - \rho_f}{\rho_f}\right)\left(\frac{D}{d}\right)$

CHAPTER V

SUGGESTIONS FOR FUTURE RESEARCH

The present results show that more of the same type, under various conditions of gravel size, meandering, etc. may be expected to yield useful results. However, they also show that, for major progress, an attempt should be made to find or create conditions where only one variable changes at a time. In particular it is essential to prevent k and F_{oo} from being unknown together. For this purpose we need (i) Flume experiments, such as are being initiated in the field under Alberta Research Council by Mr. C. R. Neill, in which a natural gravel is used and the D/d ratio is small enough, or the q is large enough, to ensure that F_{bo} depends on gravel size alone and not on flow characteristics, (ii) River observations, where there is bed load charge only at high discharges and, there is no suspended load. Such observations are being made at lake outlets in British Columbia this summer by Mr. R. Kellerhals and could be made, possibly in Alberta also, e.g., at the exit from Lesser Slave Lake. Both these actions together might lead to accurate assessment of F_{bo} from D and thence to accurate knowledge about k. Thereafter analysis of more general river conditions could proceed with F_{bo} known and k fairly known in advance.

Other matters deserving attention are: (i) The use of sonic sounders for recording changing bed conditions. (ii) Measurment of suspended load. (iii) Measurements by weight (in stone analysis) even for single stones. (iv) The recording of length, breadth and thickness for stones, particularly with a view to testing whether there are special rivers with peculiarly shaped stones that may give peculiar values of F_{bo}.

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APPENDIX 'A'

LIST OF SYMBOLS.

α = Thickness of stone in inches.

α_{50} = Median thickness of stone in inches.

B = Water surface breadth.

b = Breadth to be used in regime slope formula.

β = Breadth of stone in inches.

C = Charge measured by weight in parts per 1×10^5 parts of water.

D = Diameter of particles or stones.

D_{mi} = Median diameter of particles or stones in inches.

d = Mean depth of flow.

F_b = Bed factor.

F_{bo} = Zero bed factor.

ϕ = Equivalent spherical diameter. Φ_{50} = Median equivalent spherical diameter in inches.

F_s = Side factor.

g = Acceleration due to gravity.

α = Length of stone in inches.

K = $3.63 g / \vartheta^{\frac{1}{4}}$

k = Meander coefficient.

μ = Coefficient of viscosity. ϑ = coefficient of kinematic viscosity = μ/ρ

λ = A coefficient in the formula $F_{bo} = \sqrt[3]{\lambda D_{mi}}$

Q = Discharge.

ρ_f = Mass density of fluid.

ρ_s = Mass density of solids.

S = Slope of water surface.

S.F. = Shape factor.

V = Mean velocity of flow.

All units are expressed in lb. ft. sec. unless or otherwise specified.

A P P E N D I X 'B'

(TABLES)

TABLE NO. 1

STONE MEASUREMENTS, SAMPLE NO. 1

(Cross Section A_2)

No.	γ in ft.	β in ft.	α in ft.	No.	γ in ft.	β in ft.	α in ft.
1	0.75	0.70	0.60	27	0.11	0.1	0.08
2	0.70	0.53	0.38	28	0.21	0.15	0.10
3	0.6	0.45	0.27	29	0.18	0.13	0.09
4	0.45	0.45	0.23	30	0.28	0.2	0.1
5	0.30	0.20	0.13	31	0.19	0.15	0.09
6	0.23	0.18	0.12	32	0.11	0.06	0.04
7	0.20	0.17	0.09	33	0.3	0.17	0.10
8	0.20	0.15	0.11	34	0.35	0.17	0.13
9	0.32	0.30	0.16	35	0.33	0.28	0.11
10	0.13	0.10	0.08	36	0.18	0.13	0.07
11	0.13	0.13	0.05	37	0.09	0.06	0.05
12	0.14	0.10	0.06	38	0.14	0.10	0.08
13	0.13	0.08	0.05	39	0.26	0.14	0.09
14	0.17	0.14	0.09	40	0.37	0.20	0.08
15	0.26	0.20	0.18	41	0.17	0.1	0.08
16	0.19	0.13	0.04	42	0.23	0.17	0.09
17	0.28	0.16	0.18	43	0.20	0.15	0.08
18	0.32	0.17	0.13	44	0.29	0.13	0.10
19	0.15	0.08	0.02	45	0.40	0.30	0.23
20	0.10	0.06	0.03	46	0.23	0.12	0.07
21	0.27	0.17	0.07	47	0.43	0.34	0.24
22	0.08	0.06	0.03	48	0.13	0.07	0.05
23	0.37	0.15	0.09	49	0.18	0.10	0.08
24	0.16	0.15	0.09	50	0.12	0.11	0.05
25	0.24	0.19	0.16	51	0.23	0.19	0.12
26	0.18	0.11	0.11	52	0.14	0.10	0.05

TABLE No. I (cont'd.)

No.	γ in ft.	β in ft.	α in ft.	No.	γ in ft.	β in ft.	α in ft.
53	0.23	0.18	0.13	81	0.35	0.19	0.12
54	0.12	0.08	0.05	82	0.42	0.27	0.15
55	0.24	0.15	0.08	83	0.46	0.37	0.18
56	0.26	0.15	0.13	84	0.23	0.20	0.14
57	0.11	0.06	0.03	85	0.20	0.14	0.08
58	0.24	0.19	0.10	86	0.23	0.16	0.10
59	0.40	0.37	0.28	87	0.33	0.18	0.15
60	0.34	0.18	0.12	88	0.19	0.18	0.10
61	0.20	0.13	0.10	89	0.27	0.22	0.10
62	0.25	0.15	0.1	90	0.43	0.35	0.18
63	0.09	0.1	0.07	91	0.43	0.26	0.25
64	0.27	0.16	0.04	92	0.4	0.32	0.2
65	0.20	0.12	0.04	93	0.25	0.15	0.05
66	0.43	0.33	0.18	94	0.28	0.23	0.12
67	0.21	0.17	0.06	95	0.16	0.13	0.09
68	0.16	0.08	0.05	96	0.37	0.27	0.20
69	0.14	0.10	0.06	97	0.38	0.30	0.21
70	0.28	0.23	0.17	98	0.57	0.34	0.26
71	0.25	0.20	0.06	99	0.23	0.14	0.06
72	0.22	0.18	0.08	100	0.09	0.07	0.06
73	0.22	0.18	0.09	101	0.38	0.33	0.18
74	0.29	0.15	0.10	102	0.23	0.18	0.10
75	0.21	0.12	0.10	103	0.29	0.22	0.17
76	0.10	0.08	0.05	104	0.24	0.16	0.12
77	0.19	0.11	0.07	105	0.32	0.23	0.24
78	0.20	0.13	0.1	106	0.31	0.17	0.08
79	0.15	0.11	0.06	107	0.18	0.17	0.08
80	0.20	0.12	0.07	108	0.17	0.13	0.05

TABLE NO. 1 (cont'd.)

No.	γ in ft.	β in ft.	α in ft.	No.	γ in ft.	β in ft.	α in ft.
109	0.21	0.15	0.08	113	0.48	0.44	0.35
110	0.39	0.30	0.20	114	0.65	0.47	0.34
111	0.07	0.04	0.04	115	0.16	0.08	0.04
112	0.08	0.05	0.03	116	0.14	0.06	0.04

TABLE NO. 2

STONE MEASUREMENTS, SAMPLE NO. 2
(Cross Section A_3)

No.	γ in ft.	β in ft.	α in ft.	ϕ in in.	No.	γ in ft.	β in ft.	α in ft.	ϕ in in.
1	0.28	0.26	0.19	3.10	28	0.48	0.27	0.25	4.20
2	0.35	0.25	0.14	3.14	29	0.38	0.35	0.10	2.30
3	0.28	0.17	0.08	1.68	30	0.41	0.35	0.16	2.96
4	0.30	0.23	0.09	2.39	31	0.29	0.23	0.09	1.82
5	0.34	0.29	0.16	3.00	32	0.24	0.20	0.11	1.85
6	0.30	0.21	0.16	2.78	33	0.23	0.15	0.10	1.84
7	0.25	0.21	0.11	2.20	34	0.19	0.13	0.07	1.41
8	0.32	0.24	0.16	2.88	35	0.15	0.10	0.03	0.78
9	0.35	0.25	0.23	3.77	36	0.20	0.14	0.03	0.80
10	0.40	0.33	0.19	3.54	37	0.16	0.13	0.08	0.65
11	0.12	0.11	0.04	0.84	38	0.19	0.13	0.10	1.70
12	0.26	0.15	0.15	2.46	39	0.11	0.08	0.04	0.82
13	0.21	0.15	0.08	1.56	40	0.10	0.06	0.04	0.82
14	0.29	0.21	0.13	3.02	41	0.27	0.22	0.09	1.89
15	0.20	0.15	0.05	1.13	42	0.23	0.13	0.04	1.00
16	0.28	0.22	0.18	3.02	43	0.25	0.12	0.04	0.92
17	0.19	0.16	0.08	1.55	44	0.14	0.09	0.04	0.86
18	0.37	0.34	0.22	3.86	45	0.17	0.13	0.05	1.08
19	0.60	0.43	0.31	5.46	46	0.09	0.07	0.06	0.97
20	0.62	0.23	0.15	3.06	47	0.09	0.06	0.06	0.95
21	0.25	0.23	0.18	2.70	48	0.12	0.09	0.05	0.96
22	0.50	0.34	0.20	3.80	49	0.13	0.10	0.07	1.23
23	0.14	0.08	0.01	3.28	50	0.14	0.08	0.02	1.13
24	0.51	0.39	0.22	3.88	51	0.17	0.16	0.09	1.63
25	0.53	0.34	0.34	4.86	52	0.11	0.08	0.05	0.92
26	0.75	0.50	0.27	4.92	53	0.15	0.11	0.09	1.50
27	0.49	0.32	0.20	4.05					

TABLE NO. 3

STONE MEASUREMENTS, SAMPLE NO. 3
(Cross Section A_4)

No.	γ in ft.	β in ft.	α in ft.	ϕ in in.	No.	γ in ft.	β in ft.	α in ft.	ϕ in in.
1	0.58	0.33	0.12	2.77	27	0.49	0.42	0.23	4.36
2	0.33	0.19	0.17	2.99	28	0.15	0.10	0.08	1.38
3	0.40	0.35	0.19	3.58	29	0.23	0.21	0.16	2.70
4	0.29	0.22	0.18	3.00	30	0.21	0.14	0.10	1.80
5	0.51	0.30	0.15	3.10	31	0.13	0.10	0.08	1.35
6	0.29	0.18	0.17	2.80	32	0.15	0.10	0.03	0.72
7	0.20	0.11	0.04	0.93	33	0.14	0.09	0.04	0.84
8	0.19	0.16	0.12	2.04	34	0.18	0.10	0.08	1.43
9	0.11	0.08	0.08	1.27	35	0.33	0.30	0.15	2.87
10	0.38	0.27	0.18	3.27	36	0.38	0.34	0.14	2.87
11	0.25	0.17	0.08	1.65	37	0.22	0.14	0.07	1.45
12	0.37	0.32	0.17	3.22	38	0.09	0.06	0.03	0.60
13	0.22	0.16	0.10	1.85	39	0.11	0.09	0.03	0.62
14	0.10	0.08	0.06	1.04	40	0.23	0.11	0.10	1.73
15	0.17	0.12	0.05	1.09	41	0.26	0.23	0.10	2.02
16	0.55	0.39	0.16	3.42	42	0.21	0.13	0.08	1.52
17	0.26	0.17	0.15	2.51	43	0.20	0.09	0.07	1.31
18	0.35	0.28	0.15	2.97	44	0.34	0.23	0.15	2.75
19	0.13	0.11	0.04	0.87	45	0.16	0.11	0.10	1.64
20	0.23	0.14	0.06	1.30	46	0.19	0.17	0.13	2.16
21	0.10	0.08	0.05	0.90	47	0.12	0.08	0.04	0.81
22	0.19	0.10	0.03	0.75	48	0.12	0.11	0.02	0.54
23	0.17	0.14	0.07	1.37	49	0.10	0.08	0.04	0.79
24	0.18	0.16	0.09	1.66	50	0.16	0.08	0.05	1.00
25	0.51	0.40	0.13	2.96	51	0.10	0.08	0.04	0.79
26	0.35	0.33	0.14	2.50	52	0.51	0.37	0.21	4.00

TABLE NO. 3 (cont'd)

No.	γ in ft.	β in ft.	α in ft.	ϕ in in.	No.	γ in ft.	β in ft.	α in ft.	ϕ in in.
53	0.48	0.38	0.12	2.73	81	0.24	0.16	0.10	1.86
54	0.15	0.10	0.08	1.38	82	0.16	0.10	0.07	1.28
55	0.25	0.15	0.06	1.34	83	0.43	0.34	0.24	4.14
56	0.10	0.09	0.05	0.93	84	0.27	0.15	0.11	2.00
57	0.22	0.17	0.14	2.40	85	0.29	0.26	0.14	2.61
58	0.42	0.18	0.10	2.10	86	0.33	0.33	0.17	3.16
59	0.14	0.09	0.07	1.23	87	0.39	0.32	0.21	3.71
60	0.19	0.18	0.12	2.10	88	0.43	0.42	0.18	3.60
61	0.43	0.35	0.19	3.74	89	0.27	0.19	0.13	2.30
62	0.34	0.26	0.17	3.04	90	0.20	0.16	0.13	2.10
63	0.32	0.21	0.13	2.50	91	0.30	0.21	0.08	1.70
64	0.20	0.15	0.09	1.70	92	0.31	0.19	0.14	2.50
65	0.28	0.22	0.08	2.10	93	0.13	0.07	0.05	0.90
66	0.42	0.29	0.11	2.44	94	0.23	0.14	0.07	1.40
67	0.22	0.10	0.06	1.21	95	0.14	0.09	0.07	1.22
68	0.25	0.18	0.11	2.62	96	0.19	0.14	0.11	1.86
69	0.39	0.32	0.19	3.52	97	0.17	0.16	0.08	1.51
70	0.26	0.22	0.12	2.26	98	0.11	0.08	0.04	0.636
71	0.20	0.17	0.09	1.74	99	0.12	0.07	0.03	0.522
72	0.24	0.13	0.06	1.30	100	0.07	0.07	0.02	0.364
73	0.18	0.12	0.06	1.20	101	0.17	0.13	0.08	1.59
74	0.20	0.19	0.10	1.87	102	0.12	0.12	0.04	0.90
75	0.23	0.20	0.14	3.40	103	0.18	0.10	0.04	0.90
76	0.13	0.09	0.05	0.97	104	0.14	0.11	0.04	0.90
77	0.26	0.17	0.09	1.80	105	0.23	0.12	0.08	1.50
78	0.12	0.11	0.06	1.20	106	0.13	0.10	0.05	1.00
79	0.22	0.12	0.08	1.60	107	0.11	0.11	0.09	1.40
80	0.24	0.08	0.06	1.20	108	0.16	0.10	0.10	1.60

TABLE NO. 3 (cont'd.)

No.	γ in ft.	β in ft.	α in ft.	ϕ in in.	No.	γ in ft.	β in ft.	α in ft.	ϕ in in.
109	0.23	0.17	0.13	2.20	124	0.16	0.13	0.08	1.56
110	0.10	0.08	0.05	0.90	125	0.12	0.09	0.07	1.11
111	0.13	0.08	0.04	0.80	126	0.23	0.14	0.10	1.80
112	0.15	0.13	0.06	1.95	127	0.17	0;11	0.06	1.17
113	0.08	0.08	0.06	0.98	128	0.12	0.09	0.06	1.06
114	0.08	0.08	0.08	1.20	129	0.19	0.12	0.07	1.34
115	0.23	0.14	0.14	2.26	130	0.10	0.10	0.08	1.28
116	0.18	0.11	0.13	0.745	131	0.25	0.23	0.16	2.70
117	0.11	0.07	0.06	0.93	132	0.39	0.37	0.12	2.62
118	0.13	0.12	0.05	1.01	133	0.54	0.37	0.18	3.63
119	0.20	0.14	0.07	1.39	134	0.46	0.38	0.19	3.70
120	0.15	0.13	0.08	1.45	135	0.45	0.34	0.21	3.83
121	0.12	0.08	0.03	0.67	136	0.52	0.43	0.25	4.60
122	0.14	0.09	0.04	0.845	137	0.80	0.61	0.37	6.24
123	0.22	0.18	0.13	2.22					

TABLE NO. 4

STONE MEASUREMENTS, SAMPLE NO. 4

No.	γ in ft.	β in ft.	α in ft.	ϕ in in.	No.	γ in ft.	β in ft.	α in ft.	ϕ in in.
1	0.45	0.33	0.21	3.86	27	0.17	0.13	0.09	1.55
2	0.42	0.37	0.19	3.62	28	0.35	0.26	0.09	2.03
3	0.44	0.30	0.25	4.24	29	0.21	0.20	0.06	1.35
4	0.48	0.53	0.37	6.05	30	0.17	0.12	0.08	1.45
5	0.24	0.17	0.12	2.00	31	0.23	0.20	0.09	1.80
6	0.24	0.14	0.08	1.60	32	0.47	0.28	0.13	2.76
7	0.25	0.23	0.09	1.88	33	0.50	0.44	0.35	5.80
8	0.17	0.15	0.10	1.75	34	0.21	0.16	0.09	1.71
9	0.47	0.36	0.18	3.56	35	0.29	0.17	0.10	2.07
10	0.33	0.24	0.13	2.53	36	0.12	0.10	0.07	1.22
11	0.24	0.17	0.15	2.50	37	0.12	0.06	0.06	1.00
12	0.16	0.12	0.06	1.20	38	0.23	0.17	0.10	1.90
13	0.75	0.50	0.25	5.05	39	0.16	0.08	0.05	0.98
14	0.20	0.16	0.12	2.40	40	0.15	0.10	0.06	1.20
15	0.13	0.13	0.07	1.30	41	0.15	0.13	0.10	1.69
16	0.18	0.13	0.06	1.40	42	0.17	0.10	0.09	1.53
17	0.11	0.07	0.03	0.65	43	0.13	0.08	0.04	0.82
18	0.44	0.35	0.16	3.25	44	0.12	0.09	0.07	1.30
19	0.21	0.13	0.06	1.25	45	0.22	0.15	0.11	1.95
20	0.29	0.28	0.17	2.40	46	0.35	0.29	0.12	2.48
21	0.20	0.20	0.09	1.73	47	0.17	0.10	0.08	1.41
22	0.17	0.12	0.08	1.50	48	0.50	0.42	0.24	4.50
23	0.11	0.10	0.07	1.20	49	0.12	0.07	0.04	0.79
24	0.16	0.14	0.07	1.35	50	0.25	0.17	0.13	2.30
25	0.21	0.16	0.10	1.84	51	0.14	0.12	0.05	1.20
26	0.13	0.07	0.04	0.80	52	0.47	0.16	0.12	2.40

TABLE NO. 4 (cont'd.)

No.	γ in ft.	β in ft.	α in ft.	ϕ in in.	No.	γ in ft.	β in ft.	α in ft.	ϕ in in.
53	0.19	0.12	0.08	1.50	81	0.16	0.14	0.07	1.35
54	0.11	0.10	0.08	1.30	82	0.20	0.11	0.08	1.48
55	0.19	0.12	0.05	1.10	83	0.55	0.41	0.71	3.60
56	0.34	0.28	0.15	2.90	84	0.17	0.14	0.06	1.23
57	0.22	0.17	0.11	2.00	85	0.23	0.14	0.12	2.06
58	0.21	0.13	0.06	1.27	86	0.10	0.08	0.03	0.65
59	0.36	0.23	0.12	2.40	87	0.48	0.42	0.20	3.92
60	0.26	0.21	0.11	2.12	88	0.34	0.22	0.16	2.90
61	0.15	0.12	0.07	1.30	89	0.12	0.10	0.06	1.10
62	0.19	0.15	0.12	2.04	90	0.41	0.30	0.15	3.00
63	0.24	0.20	0.14	2.42	91	0.46	0.27	0.16	3.10
64	0.12	0.11	0.07	1.23	92	0.24	0.18	0.15	2.50
65	0.14	0.10	0.04	0.87	93	0.47	0.35	0.18	3.55
66	0.20	0.18	0.18	2.82	94	0.43	0.30	0.22	3.90
67	0.20	0.19	0.12	2.12	95	0.18	0.13	0.04	0.94
68	0.19	0.10	0.09	1.56	96	0.13	0.09	0.05	0.98
69	0.39	0.31	0.16	3.00	97	0.32	0.22	0.18	3.10
70	0.16	0.12	0.10	1.70	98	0.36	0.15	0.10	2.00
71	0.20	0.13	0.08	1.50	99	0.25	0.19	0.07	1.53
72	0.26	0.21	0.10	2.00	100	0.27	0.20	0.18	2.94
73	0.25	0.24	0.10	2.02	101	0.43	0.32	0.32	5.05
74	0.17	0.11	0.11	1.62	102	0.21	0.09	0.07	1.32
75	0.17	0.15	0.09	1.64	103	0.20	0.18	0.11	1.97
76	0.67	0.36	0.17	3.64	104	0.20	0.15	0.12	2.05
77	0.30	0.23	0.10	2.10	105	0.31	0.24	0.16	2.90
78	0.28	0.19	0.16	2.72	106	0.29	0.21	0.13	2.42
79	0.17	0.14	0.10	1.73	107	0.21	0.16	0.09	1.70
80	0.12	0.11	0.10	1.58	108	0.16	0.11	0.07	1.30
					109	0.15	0.10	0.09	1.51

TABLE NO. 5

A SAMPLE OF CALCULATIONS FOR ANALYSIS OF BED-LOAD SAMPLE NO. 4
(Cross Section A_5)

ϕ in inches	No. of Stones	Cumulative number of stones	Percentage by no. ϕ equalled or exceeded	$n\phi^3$	$\Sigma n\phi^3$	Percentage by wt. equalled or exceeded	ϕ/ϕ_{50} (By number) $\phi_{50} = 1.9''$	ϕ/ϕ_{50} (By weight) $\phi_{50} = 3.9''$
6.05	1	1	0.92	222	222	11.0	3.18	1.55
5.8	1	2	1.84	194	426	21.6		
5.05	2	4	3.67	260	686	25.0		
4.5	1	5	4.58	91	777	38.4		
4.24	1	6	5.5	76	853	42.2	2.24	1.09
3.92	1	7	6.42	60	913	45.1		
3.90	1	8	7.34	60	973	48.0		
3.86	1	9	8.25	58	1031	51.1		
3.64	1	10	9.15	49	1080	53.4	1.92	0.93
3.62	1	11	10.1	47	1127	55.6		
3.60	1	12	11.0	46	1173	58.0		
3.56	1	13	11.93	45	1218	60.2		
3.55	1	14	12.85	45	1263	62.4	1.87	0.91
3.25	1	15	13.75	37	1300	64.2		

TABLE NO. 5 (cont'd.)

ϕ in inches	No. of Stones	Cumulative number of stones	Percentage by no. ϕ equalled or exceeded	$n\phi^3$	$\Sigma n\phi^3$	Percentage by wt. ϕ equalled or exceeded	ϕ/ϕ_{50} (By number), ϕ_{50} = 1.9"	ϕ/ϕ_{50} (By weight), ϕ_{50} = 3.9"
3.10	2	17	15.60	60	1360	67.2		
3.0	2	19	17.40	54	1414	70.0	1.58	0.77
2.94	1	20	18.35	25	1439	71.0		
2.90	3	23	21.1	72	1511	74.6		
2.82	1	24	22.0	22	1533	75.6	1.49	0.72
2.76	1	25	22.90	21	1554	76.6		
2.72	1	26	23.80	20	1574	77.8		
2.53	1	27	24.78	16	1590	78.5	1.33	0.65
2.50	2	29	26.6	32	1622	80.2	1.31	0.64
2.48	1	30	27.50	15	1637	80.8		
2.42	2	32	29.3	28	1665	81.8		
2.40	4	36	33.0	55	1720	85	1.26	0.62
2.30	1	37	33.9	12	1732	85.6		
2.12	2	39	35.8	20	1752	86.5		
2.10	1	40	36.7	9	1761	87.0	1.11	0.54
2.07	1	41	37.6	9	1770	87.50		
2.06	1	42	38.5	9	1779	87.9		

TABLE NO. 5 (cont'd.)

ϕ in inches	No. of Stones	Cumulative number of stones	Percentage by no. ϕ equalled or exceeded	$n\phi^3$	$\Sigma n\phi^3$	Percentage by wt. ϕ equalled or exceeded	ϕ/ϕ_{50} (By number), ϕ_{50} = 1.9"	ϕ/ϕ_{50} (By weight), ϕ_{50} = 3.9"
2.05	1	43	39.4	9	1788	88.40	1.08	0.53
2.04	1	44	40.4	8	1796	88.60		
2.03	1	45	41.3	8	1804	89.2		
2.02	1	46	42.2	8	1812	89.60		
2.0	4	50	45.8	32	1844	91.10	1.05	0.51
1.97	1	51	46.7	8	1852	91.50		
1.95	1	52	47.60	7	1859	91.80		
1.90	1	53	48.60	7	1866	92.2		
1.88	1	54	49.50	7	1873	92.5	0.99	0.48
1.84	1	55	50.40	6	1879	92.8		
1.80	1	56	51.40	6	1885	93.2		
1.75	1	57	52.2	5	1890	93.4	0.92	0.45
1.73	2	59	54.1	10	1900	93.8		
1.71	1	60	55.0	5	1905	94.2		
1.70	2	62	56.8	10	1915	94.5	0.90	0.44
1.69	1	63	57.6	5	1920	94.80		
1.64	1	64	58.6	4	1924	95.1		0.42

TABLE NO. 5 (cont'd.)

ϕ in inches	No. of Stones	Cumulative number of stones	Percentage by no. ϕ equalled or exceeded	$n\phi^3$	$\Sigma n\phi^3$	Percentage by wt. ϕ equalled or exceeded	ϕ/ϕ_{50} (By number), $\phi_{50} = 1.9"$	ϕ/ϕ_{50} (By weight) $\phi_{50} = 3.9"$
1.62	1	65	59.6	4	1928			
1.60	1	66	60.5	4	1932		0.85	
1.58	1	67	61.4	4	1936			
1.56	1	68	62.4	4	1940			
1.55	1	69	63.3	4	1944		0.82	
1.53	2	71	65.2	8	1952			
1.51	1	72	66.0	3	1955	96.5		
1.50	3	75	68.8	9	1964		0.79	0.39
1.48	1	76	69.6	3	1967			
1.45	1	77	70.5	3	1970			
1.41	1	78	71.50	3	1973			
1.40	1	79	72.50	3	1976		0.74	
1.35	3	82	75.2	7	1983			
1.32	1	83	76.20	2	1985	98.0		0.34
1.30	5	88	80.50	11	1996		0.69	
1.27	1	89	81.50	2	1998			
1.25	1	90	82.5	2	2000	98.9		0.32

TABLE NO. 5 (cont'd.)

ϕ in inches	No. of Stones	Cumulative number of stones	Percentage by no. ϕ equalled or exceeded	$n\phi^3$	$\Sigma n\phi^3$	Percentage by wt. ϕ equalled or exceeded	ϕ/ϕ_{50} (By number), ϕ_{50} = 1.9"	ϕ/ϕ_{50} (By weight), ϕ_{50} = 3.9"
1.23	2	92	84.4	4	2004		0.65	
1.22	1	93	85.20	2	2006			
1.20	4	97	89.00	7	2013			
1.1	2	99	90.80	3	2016	99.40	0.58	0.28
1.0	1	100	91.6	1.0	2017		0.53	
0.98	2	102	93.5	1.9	2018.9			
0.94	1	103	94.5	0.8	2019.7			
0.87	1	104	95.5	0.7	2020.4		0.46	
0.82	1	105	96.5	0.6	2021.0			
0.80	1	106	97.40	0.5	2021.5		0.42	
0.79	1	107	98.20	0.5	2022.0	99.99		
0.65	2	109	100	0.6	2022.6			

TABLE NO. 6

RESULTS OF ANALYSIS OF SIZE DISTRIBUTION OF GRAVEL

S.No.	Sample Site	No. of Stones	α max. in in.	α min. in in.	α_{50} by no. in in.	α_{50} by wt. in in.	ϕ_{50} by no. in in.	ϕ_{50} by wt. in in.	Range of sizes from 1% to 99%	Fig.Nos. for Plots	Fig.Nos. for Photos	Remarks
1	A_2	116	7.20	0.36	1.3	4.0	-	-	15	14 & 15	126	
2	A_3	53	4.08	0.12	-	-	1.95	3.90	21	16 & 17	127	
3	A_4	137	6.84	0.36	-	-	1.75	3.60	12	18 & 19	-	
4	A_5	109	6.05	0.65	-	-	1.90	3.90	10	20 & 21	128	
5	A_6	129	6.16	0.53	-	-	2.20	3.90	10	22 & 23	-	Fairly
6	A_7	149	5.16	0.24	1.45	2.90	-	-	12	24 & 25	-	logar-
7	A_8	151	4.08	0.36	1.35	2.60	-	-	9	26 & 27	129	ithmic
8	A_9	100	4.80	0.36	1.30	2.80	-	-	10	28 & 29	130	normal
9	A_{10}	111	3.88	0.25	1.25	2.70	-	-	14	30 & 31	-	distri-
10	A_{11}	100	3.50	0.19	1.25	2.25	-	-	11	32 & 33	-	bution
11	A_{12}	61	3.13	0.25	1.10	2.50	-	-	20	34 & 35	-	
12	A_{13}	- Artificial section. (Gravel operations were carried on. Therefore no analysis has been done for it.)										
13	A_{29}	93	3.60	0.36	1.70	2.60	-	-	5	36 & 37	-	
14	A_{30}	73	4.56	0.36	1.35	2.60	-	-	10	38 & 39	-	
15	A_{31}	94	3.24	0.36	1.40	2.30	-	-	8	40 & 41	-	
Composite* Sample	-	-	-	-	1.35	2.80	1.90	3.60	10	42 to 45	-	

* Composite sample is the one that is obtained by mixing the individual samples. It is also the average sample.

TABLE NO. 7

RESULTS OF SIEVE ANALYSIS OF COMPOSITE SAMPLE

Median size of bed-load material
in inches

Including fine materials*			Excluding fine materials*			
Sample (by weight)			Sample (by number)		Sample (by weight)	
Surface	Total	Subsurface	Surface	Total	Surface	Subsurface
3.0	1.30	0.64	1.40	3.0	0.70	2.0

* "Fine material" includes anything passing through $\frac{1}{2}$" sieve.

TABLE NO. 8

MEANDER COEFFICIENTS FOR STEEP SECTIONS

1 Cross Sections	2 Sope of W. Surface S	3 Breadth b in ft.	4 Discharge Q in cfs.	5 Values of k for zero bed factors of 4	5	6	Remarks
A_3	1/530	318	1210	4.5	3.7	3.1	Sinusoidal bend, broad & shallow section
A_7	1/680	290	2060	3.6	3.0	2.5	Straight; broad, shallow & braided section
A_8	1/670	236	1190	3.4	2.9	2.3	Start of severe bend, narrow & fairly deep section
A_{11}	1/880	350	1210	2.8	2.4	1.9	Straight, broad & shallow section
A_{15}	1/950	317	1160	3.1	2.7	2.2	Moderate bend, broad, shallow & braided section
A_{17}	1/800	230	942	2.8	2.4	1.9	Sinusoidal bend, narrow & deep section
A_{20}	1/650	203	942	3.3	2.8	2.3	Middle of severe bend, narrow & deep section
A_{21}	1/720	190	927	3.0	2.5	2.0	Middle of severe bend, narrow & deep section
A_{23}	1/1090	190	927	2.0	1.6	1.4	Start of severe bend, narrow & deep section
A_{24}	1/1130	195	927	2.0	1.6	1.3	Middle of severe bend, narrow & deep section
A_{28}	1/320	169	830	6.5	5.3	4.5	Severe bend, narrow & deep section
A_{30}	1/590	157	870	3.5	2.9	2.4	Start of severe bend, broad & shallow section
A_{31}	1/510	270	870	4.4	3.6	3.1	Start of severe bend, broad & shallow section
A_{32}	1/1090	180	807	1.9	1.6	1.3	Middle of severe bend, narrow & steep section
A_{33}	1/980	300	807	2.3	1.9	1.6	End of severe bend, broad & shallow section

TABLE NO. 8 (cont'd)

1	2	3	4	5			6
Cross Section	Slope of W. Surface S	Breadth b in ft.	Discharge Q in cfs.	Values of k for zero bed factors of 4	5	6	Remarks
A_{34}	1/870	224	807	2.5	2.0	1.7	Sinusoidal to a little extent, narrow & deep section.
A_{35}	1/600	238	807	3.7	3.0	2.5	Start of severe bend, broad & deep section
A_{36}	1/550	240	807	4.0	3.3	2.8	Middle of severe bend, broad & shallow

TABLE NO. 9

VALUES OF CHARGE FOR VARIOUS FLOODS
AS ASSESSED FROM THE REGIME SLOPE FORMULA

Flood % by time equalled or exceeded	Quantity of Flood in cfs.	Charge "C" in parts per 1 x 10^5 parts of water by wt.	Remarks
1%	80,000	4.50	
2%	65,000	4.45	
5%	47,000	4.05	
10%	35,000	3.75	Fairly good
20%	25,000	3.36	results.
25%	22,000	3.26	
30%	19,500	3.08	
33%	17,000	2.98	
40%	16,000	2.88	
50%	13,000	2.60	
60%	10,500	2.40	
70%	8,400	2.20	
Max. so far	56,000	3.94	

TABLE NO. 10

VALUES OF λ IN THE FORMULA $F_{bo} = \sqrt[3]{\lambda D_{mi}}$

FOR $F_{bo} = 4.0$

Sample Taken from Cross Section	BY NUMBER				BY WEIGHT			
	$D_{mi} = \alpha_{50}$ in in.	λ	$D_{mi} = \phi_{50}$	λ	$D_{mi} = \alpha_{50}$ in in.	λ	$D_{mi} = \phi_{50}$ in in.	λ
A_2	1.30	50	2.02	32	4.0	16	6.2	10
A_3	1.26	51	1.95	33	2.52	25	3.90	16
A_4	1.13	57	1.75	37	2.32	28	3.60	18
A_5	1.23	52	1.90	34	2.52	25	3.90	16
A_6	1.42	45	2.20	29	2.52	25	3.90	16
A_7	1.45	44	2.24	29	2.90	22	4.5	14
A_8	1.35	48	2.09	30	2.60	25	4.04	16
A_9	1.3	50	2.01	32	2.80	23	4.34	15
A_{10}	1.25	51	1.94	33	2.70	24	4.18	15
A_{11}	1.25	51	1.94	33	2.25	28	3.5	18
A_{12}	1.10	58	1.70	38	2.50	26	3.88	17
A_{29}	1.70	38	2.63	24	2.6	25	4.04	16
A_{30}	1.35	48	2.09	31	2.6	25	4.04	16
A_{31}	1.40	46	2.17	29	2.3	28	3.56	18

TABLE NO. 11

MEASUREMENTS AND OBSERVATIONS MADE IN THE FLUME EXPERIMENT

(1.7 MM. GRAVEL)

RUN NO.	Test No.	Q in cfs.	Mean Depth in flow ft.	Mean Velocity ft./sec.	Remarks
1	1	4.4	1.15	1.31	Sheet flow
	2	4.4	1.13	1.34	*Could be F_{bo} conditions - very very slight movement by rolling
	3	4.4	1.12	1.35	Dunes - Indefinite. Appreciable movement by rolling and sliding
	4	4.4	1.10	1.37	Dunes - slightly definite
2	5	1.95	0.60	1.11	Slight sheet flow
	6	1.95	0.55	1.20	Slight sheet flow
	7	1.95	0.50	1.34	Sheet flow
	8	1.95	0.48) 0.47)	1.42	*Could be F_{bo} conditions
	9	1.95	0.40	1.67	Dunes
	10	1.95	0.45	1.48	Appreciable movement of the grains by rolling
3	11	2.10	0.70	1.03	Bed inactive
	12	2.10	0.65	1.11	Bed inactive
	13	2.10	0.60	1.20	Slight sheet flow
	14	2.10	0.58	1.24	Slight sheet flow
	15	2.10	0.57	1.27	Sheet flow
	16	2.10	0.54	1.33	Sheet flow
	17	2.10	0.52	1.39	Sheet flow
	18	2.10	0.50	1.44	*Could be F_{bo} conditions - very slight movement by rolling and sliding.
	19	2.10	0.49	1.47	Dunes indefinite

TABLE No. 11 (cont'd.)

Run No.	Test No.	Q in cfs.	Mean Depth in flow ft.	Mean Velocity Ft./sec.	Remarks
3	20	2.10	0.48	1.50	Dunes indefinite
	21	2.10	0.45	1.60	Dunes indefinite
4	22	2.47	0.83	1.02	Bed inactive
	23	2.47	0.82	1.03	Sheet flow
	24	2.47	0.75	1.13	Sheet flow
	25	2.47	0.69	1.23	Sheet flow
	26	2.47	0.68	1.25	Sheet flow
	27	2.47	0.66	1.28	Sheet flow
	28	2.47	0.61	1.39	Movement (small) by rolling may be $\frac{1}{4}$". Could be F_{bo} condition
	29	2.47	0.60	1.41	*Could be F_{bo} conditions - Movement may be $\frac{1}{4}$" - less than $\frac{1}{4}$"
	30	2.47	0.58	1.46	Indefinite dune formation
5	31	3.00	0.92	1.12	Sheet flow
	32	3.00	0.85	1.21	Sheet flow
	33	3.00	0.79	1.3	Sheet flow
	34	3.00	0.73	1.41	Sheet flow (slight movement by rolling) could be F_{bo} condition
	35	3.00	0.72	1.43	*Could be F_{bo} conditions (very slight movement by rolling) Rolling may be $\frac{1}{4}$" - $\frac{1}{2}$"
	36	3.00	0.65	1.58	Dune formation (very large movement by rolling
	37	3.00	0.68	1.51	Large movement by rolling & sliding
	38	3.00	0.69	1.49	Large movement by rolling & sliding
6	39	3.47	0.95	1.25	Sheet flow
	40	3.47	0.90	1.32	Slight sheet flow
	41	3.47	0.88	1.35	Sheet flow
	42	3.47	0.85	1.40	Sheet flow

TABLE NO. 11 (cont'd.)

Run No.	Test No.	Q in cfs.	Mean Depth in flow ft.	Mean Velocity Ft./sec.	Remarks
6	43	3.47	0.82	1.45	Appreciable movement by rolling. May be more than $\frac{1}{2}$" on average
	44	3.47	0.83	1.43	*Could be F_{bo} conditions
	45	3.47	0.80	1.49	Very small (indefinite dune formation)
7	46	4.08	1.10	1.27	Very slight shee flow
	47	4.08	1.08	1.30	Sheet flow
	48	4.08	1.01	1.39	Sheet flow
	49	4.08	0.97	1.44	Very slight movement by rolling (May be F_{bo} condition)
	50	4.08	0.98	1.43	*Could be F_{bo} conditions. (Very very small movement by rolling - may be $\frac{1}{4}$" - $\frac{1}{2}$"
	51	4.08	0.90	1.56	Large movement by rolling, by sliding, rolling & little saltation. (Indefinite dune formation)
	52	4.08	0.95	1.48	Rapid movement by rolling ($\frac{1}{2}$" or so)
	53	4.08	0.94	1.49	Movement by rolling - more than $\frac{1}{2}$"
8	54	5.0	1.40	1.22	Sheet flow
	55	5.0	1.37	1.25	Sheet flow
	56	5.0	1.36	1.26	Sheet flow (occasional rolling). $\frac{1}{2}$" May be F_{bo} condition
	57	5.0	1.35	1.27	*Could be F_{bo} conditions (Bed may be on the point of moving)
9	58	5.52	1.50	1.26	Sheet flow
	59	5.52	1.45	1.31	Slight movement by rolling ($\frac{1}{2}$" or so) - could be F_{bo} conditions
	60	5.52	1.42	1.33	Slight movement by rolling - could be F_{bo} conditions
	61	5.52	1.43	1.32	*Could be F_{bo} conditions - slight movement by rolling ?

TABLE NO. 11 (cont'd.)

Run No.	Test No.	Q in cfs.	Mean Depth in flow ft.	Mean Velocity Ft./sec.	Remarks
9	62	5.52	1.39	1.36	Large movement by rolling (More than 1")
	63	5.52	1.38	1.37	Large movement by rolling and sliding (Indefinite) Dune formation.

* It was considered as F_{bo} conditions.

TABLE NO. 12

CALCULATIONS FOR THE ANALYSIS OF THE FLUME EXPERIMENT DATA

Note: (Breadth of waterway, b = 2.92 ft.)

Run No.	Q Discharge in cfs.	d Mean depth of flow in ft.	V Mean Velocity in ft./sec.	$F_{bo} = \frac{V^2}{d}$	D/d	$\frac{VD}{\nu}$	$g(\frac{\rho_s - \rho_f}{\rho_f})(\frac{D}{d})$
					$\times 10^{-3}$	$\times 10^{2}$	$\times 10^{-2}$
1	4.4	1.13	1.34	1.59	4.95	7.45	22.3
2	1.95	0.47	1.42	4.28	11.90	7.90	53.5
3	2.10	0.50	1.44	4.16	11.20	8.0	50.4
4	2.47	0.60	1.41	3.30	9.30	7.85	41.80
5	3.00	0.72	1.43	3.08	7.75	7.95	34.90
6	3.47	0.83	1.43	2.48	6.23	7.95	28.0
7	4.08	0.98	1.43	2.10	5.70	7.95	25.70
8	5.0	1.35	1.27	1.19	4.14	8.91	18.60
9	5.52	1.43	1.32	1.22	3.90	7.35	17.60

A P P E N D I X 'C'

(FIGURES)



FIG. 1. AERIAL PHOTOGRAPH SHOWING THE RED DEER RIVER

LEGEND: A_1 —— CROSS SECTION NO.

83 —— WATER SURFACE SLOPE STATION NO.

SCALE 1" = 3333'



FIG·2· AERIAL PHOTOGRAPH SHOWING THE RED DEER RIVER

LEGEND: A_3 —— CROSS SECTION NO·
78 —— WATER SURFACE SLOPE STATION NO· SCALE 1"=3333'



FIG·3· AERIAL PHOTOGRAPH SHOWING THE RED DEER RIVER

LEGEND: A_7 —— CROSS SECTION NO·

65 —— WATER SURFACE SLOPE STATION NO·

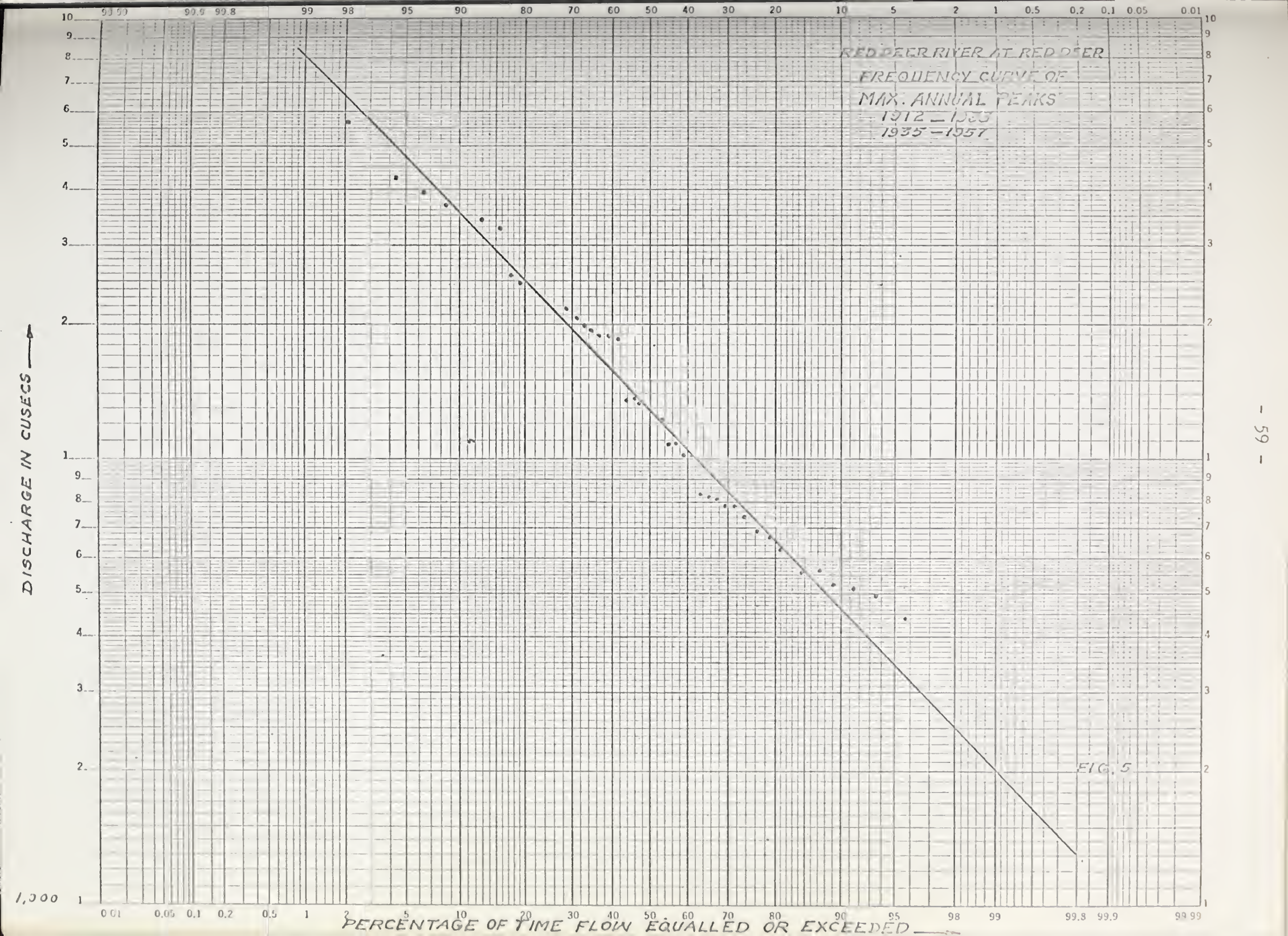
SCALE 1"=3333'

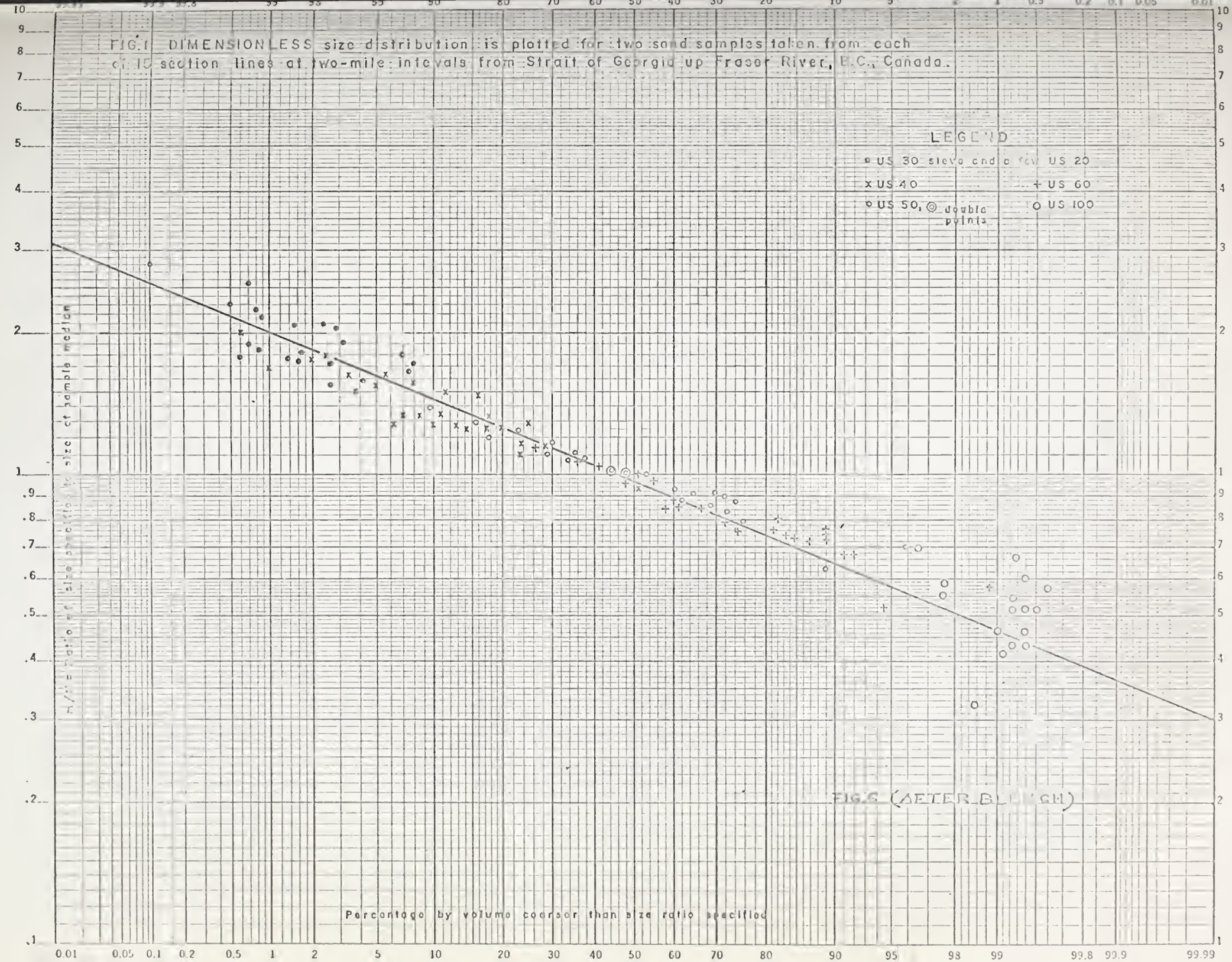


FIG. 4. AERIAL PHOTOGRAPH SHOWING THE RED DEER RIVER

LEGEND A_{18} —— CROSS SECTION NO.

39 —— WATER SURFACE SLOPE STATION NO. SCALE 1"=3333'


RED DEER RIVER AT RED DEER
FREQUENCY CURVE OF
MAX. ANNUAL PEAKS
1912 – 1933
1935 – 1957
FIG. 5
DISCHARGE IN CUSECS
PERCENTAGE OF TIME FLOW EQUALLED OR EXCEEDED
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
1,000
10 9 8 7 6 5 4 3 2 1


FIG. 1 DIMENSIONLESS size distribution is plotted for two sand samples taken from each of 10 section lines at two-mile intervals from Strait of Georgia up Fraser River, B.C., Canada.
LEGEND
US 30 sieve and a few US 20
x US 40
+ US 60
US 50, ◎ double points
US 100
Percentage by volume coarser than size ratio specified
FIG. 6 (AFTER BAGNOLD)

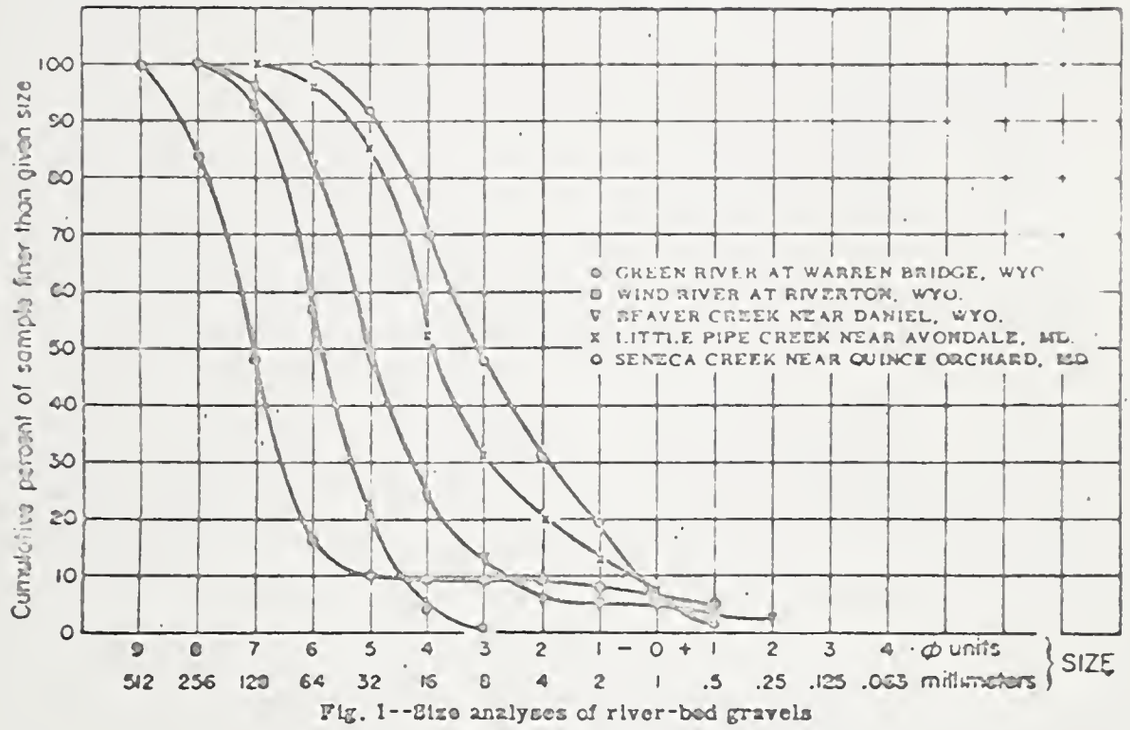


Fig. 1--Size analyses of river-bed gravels

FIG. 7. (AFTER WOLMAN)

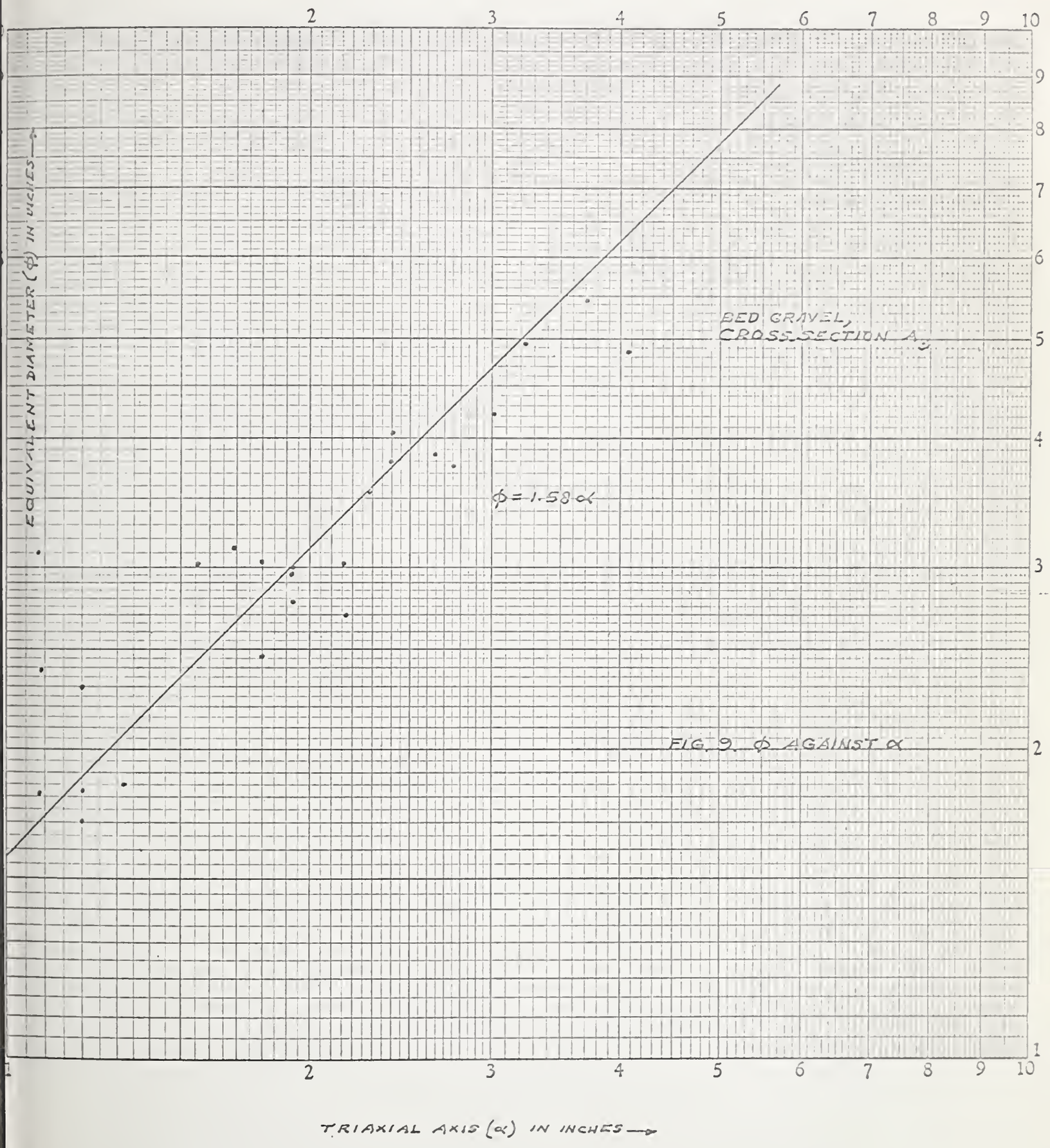


FIG. 9. φ AGAINST α

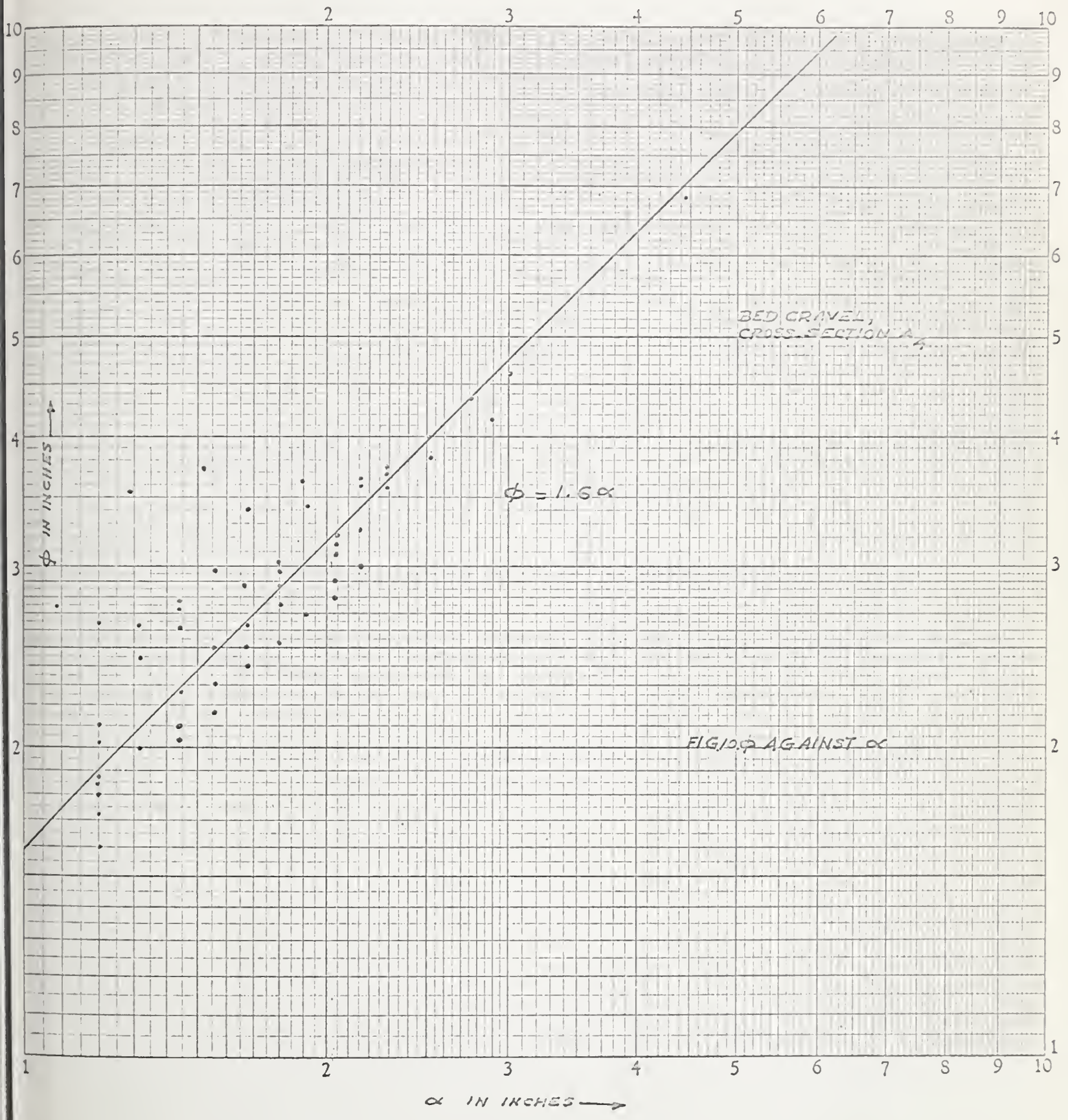


FIG. 10 ϕ AGAINST α

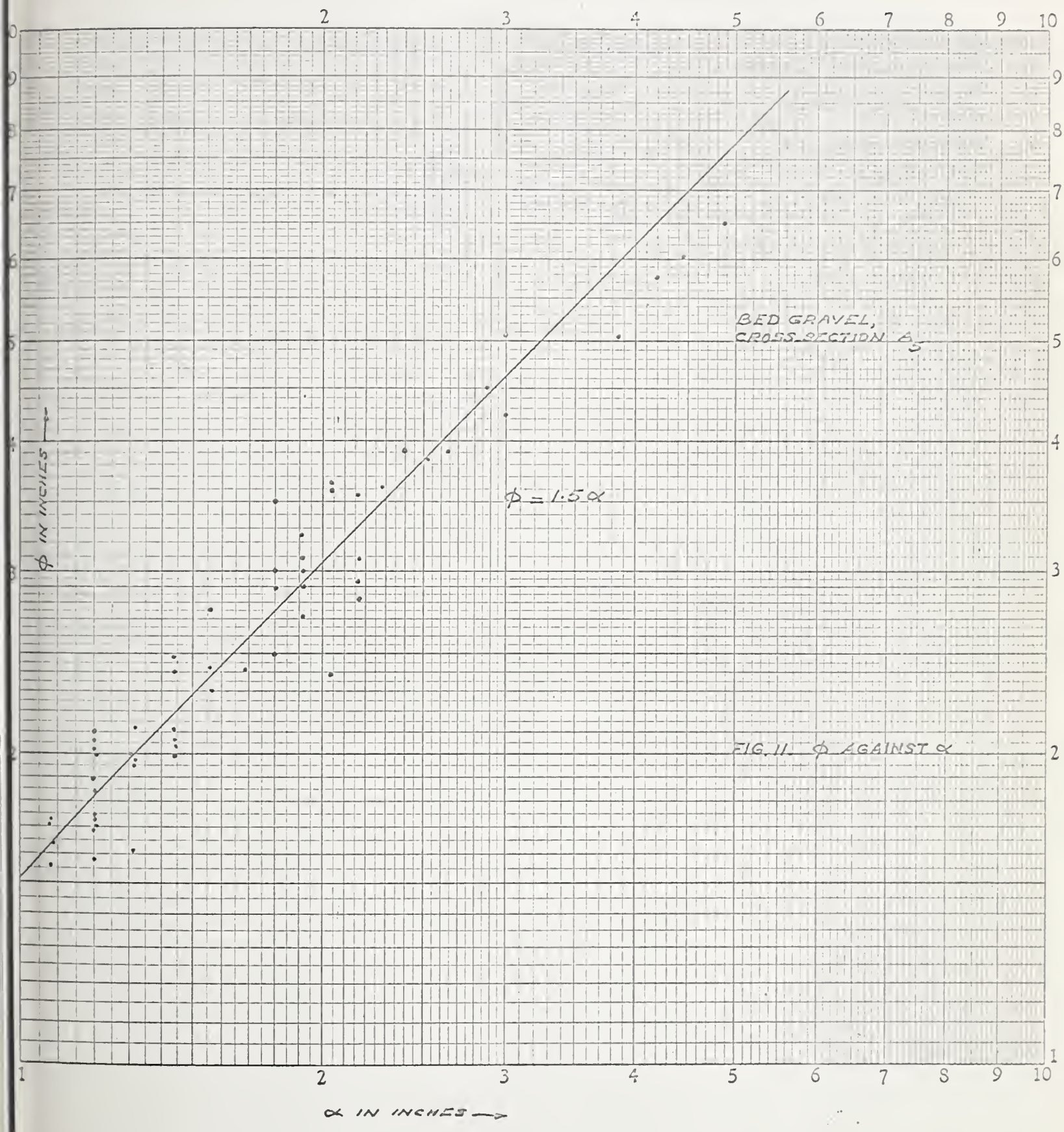


FIG. 11. ϕ AGAINST α

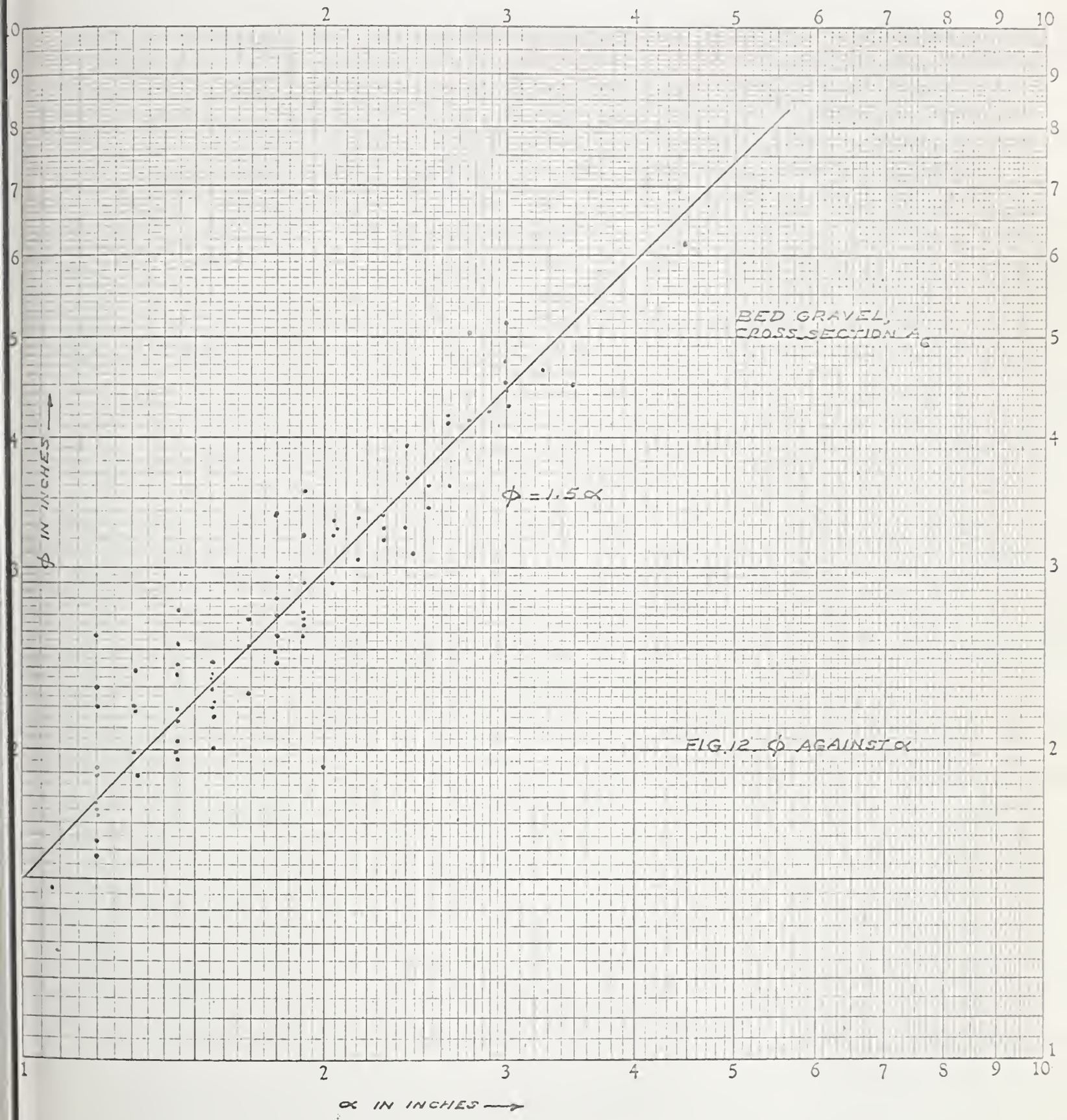


FIG. 12 ϕ AGAINST α

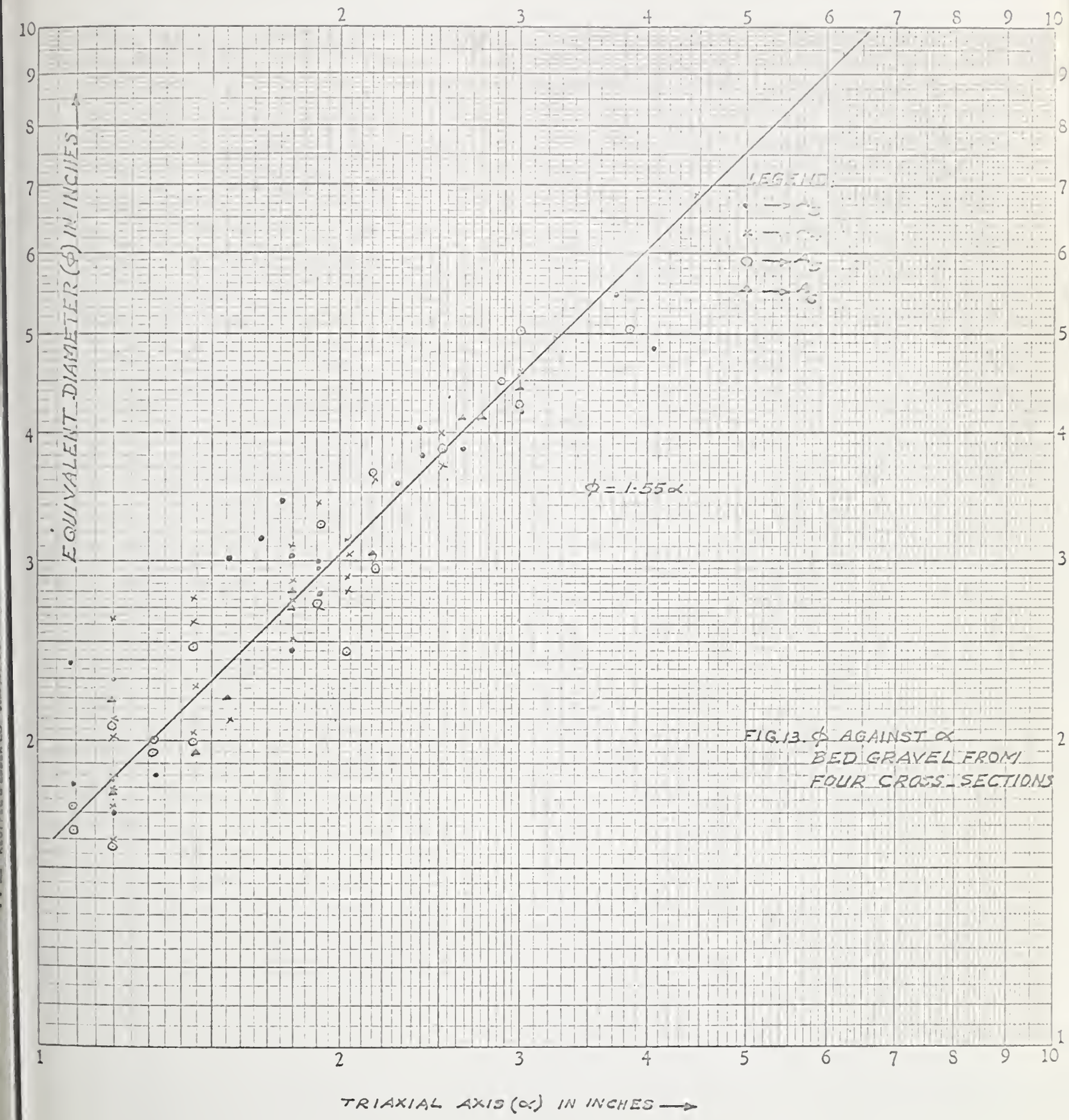
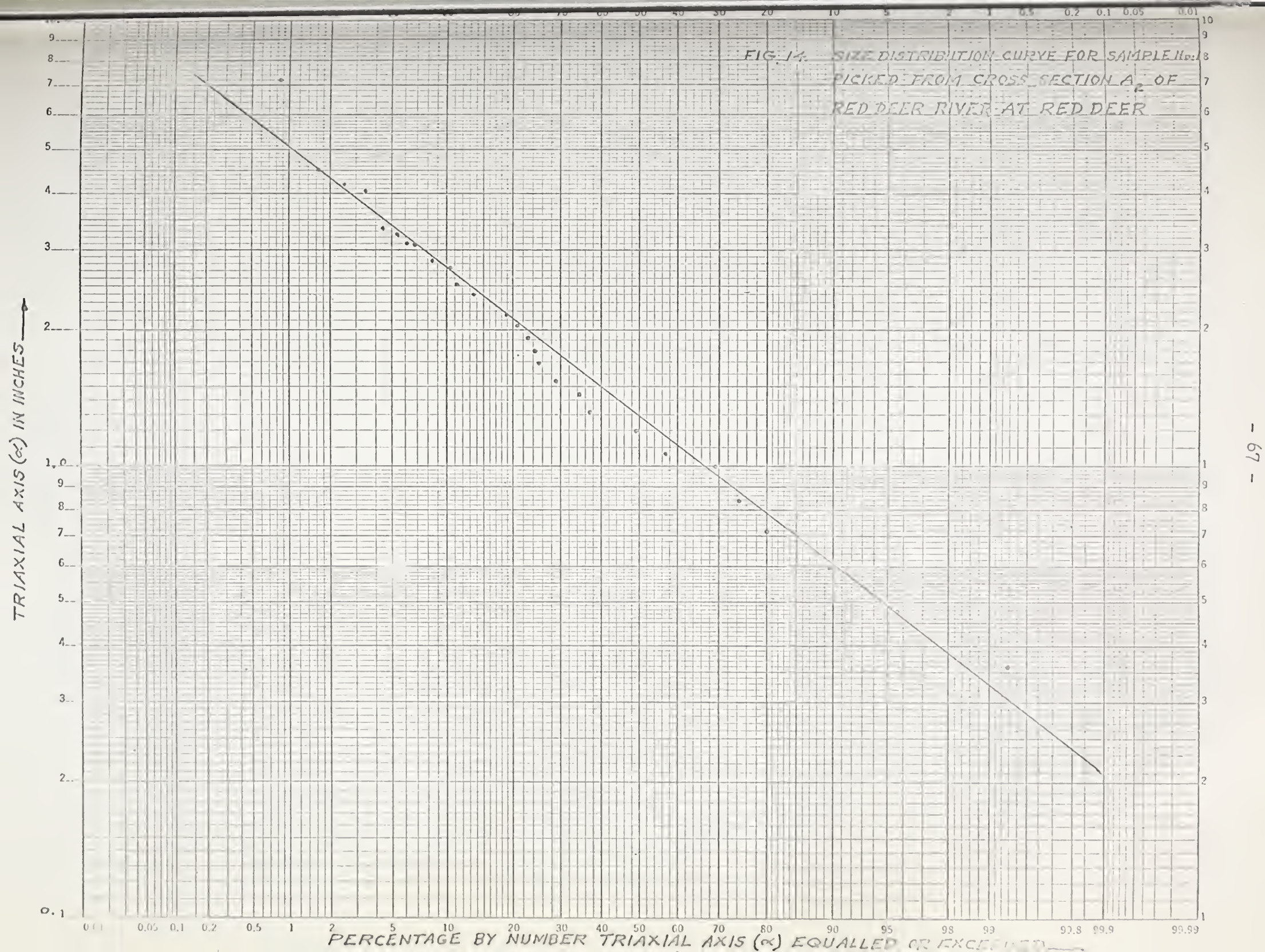


FIG. 13. Φ AGAINST α BED GRAVEL FROM FOUR CROSS-SECTIONS


FIG. 14. SIZE DISTRIBUTION CURVE FOR SAMPLE No. 1 PICKED FROM CROSS SECTION A2 OF RED DEER RIVER AT RED DEER
TRIAXIAL AXIS (α) IN INCHES
PERCENTAGE BY NUMBER TRIAXIAL AXIS (α) EQUALLED OR EXCEEDED
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
10 9 8 7 6 5 4 3 2 1.0 9 8 7 6 5 4 3 2 0.1

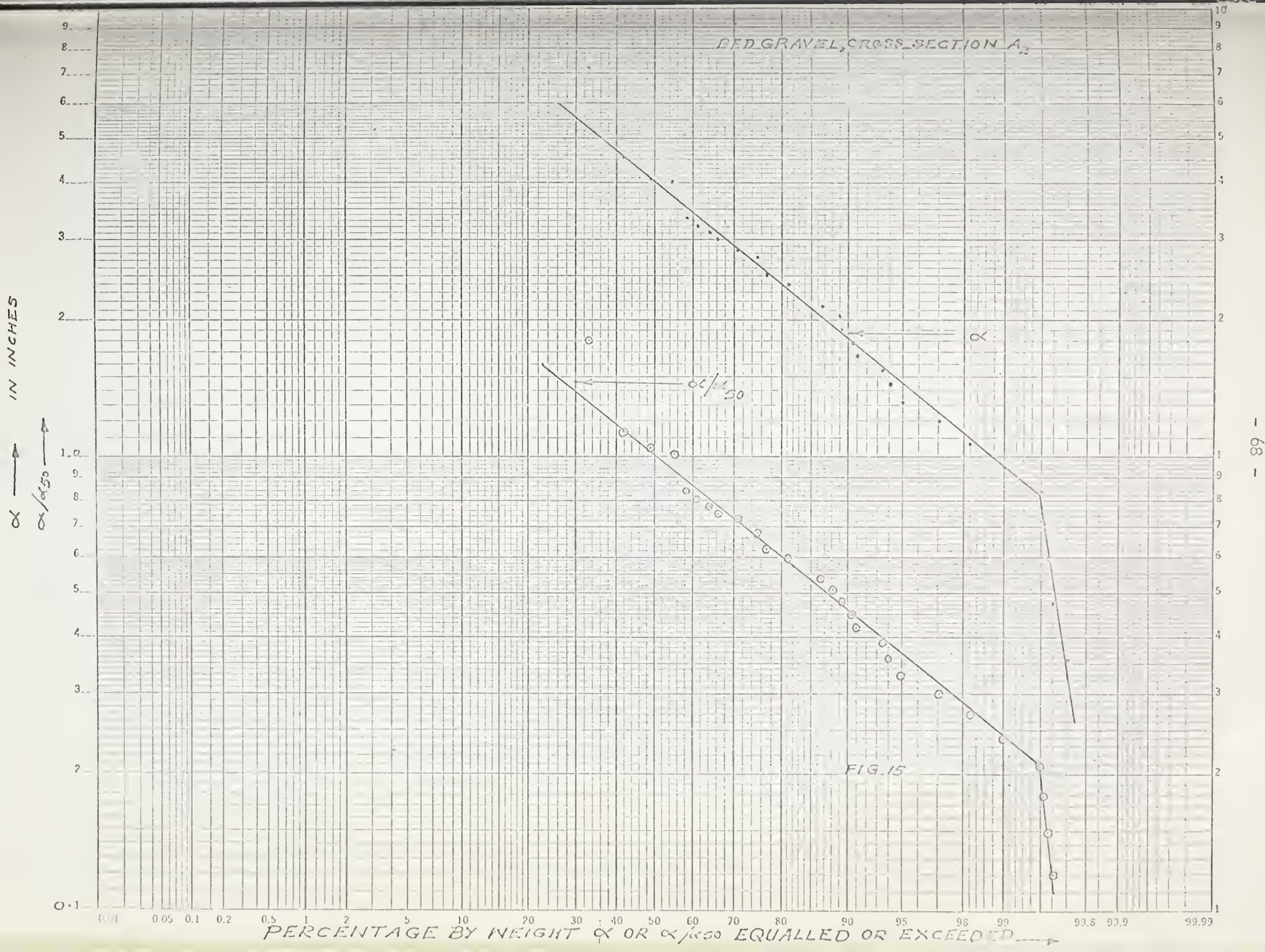
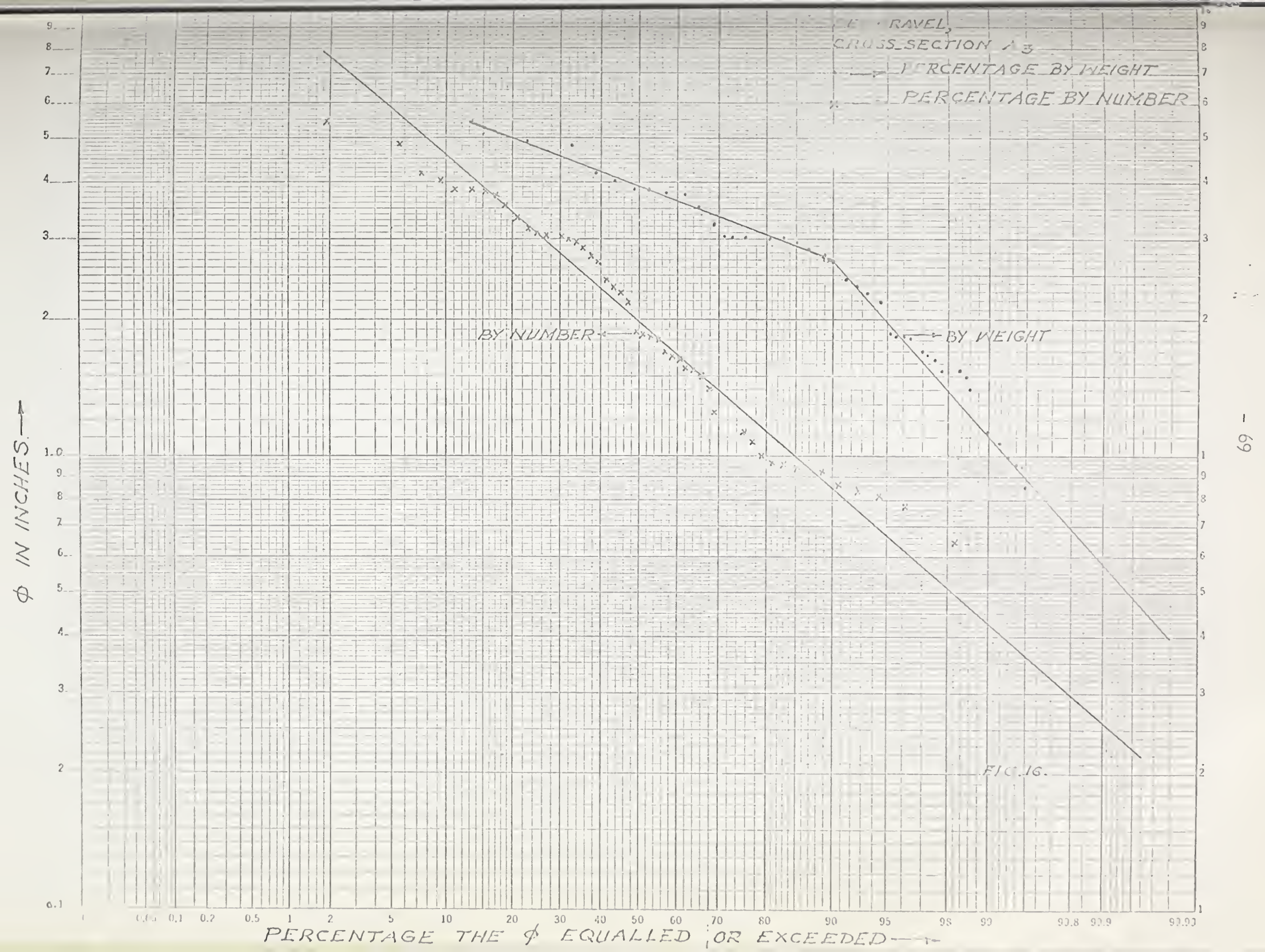
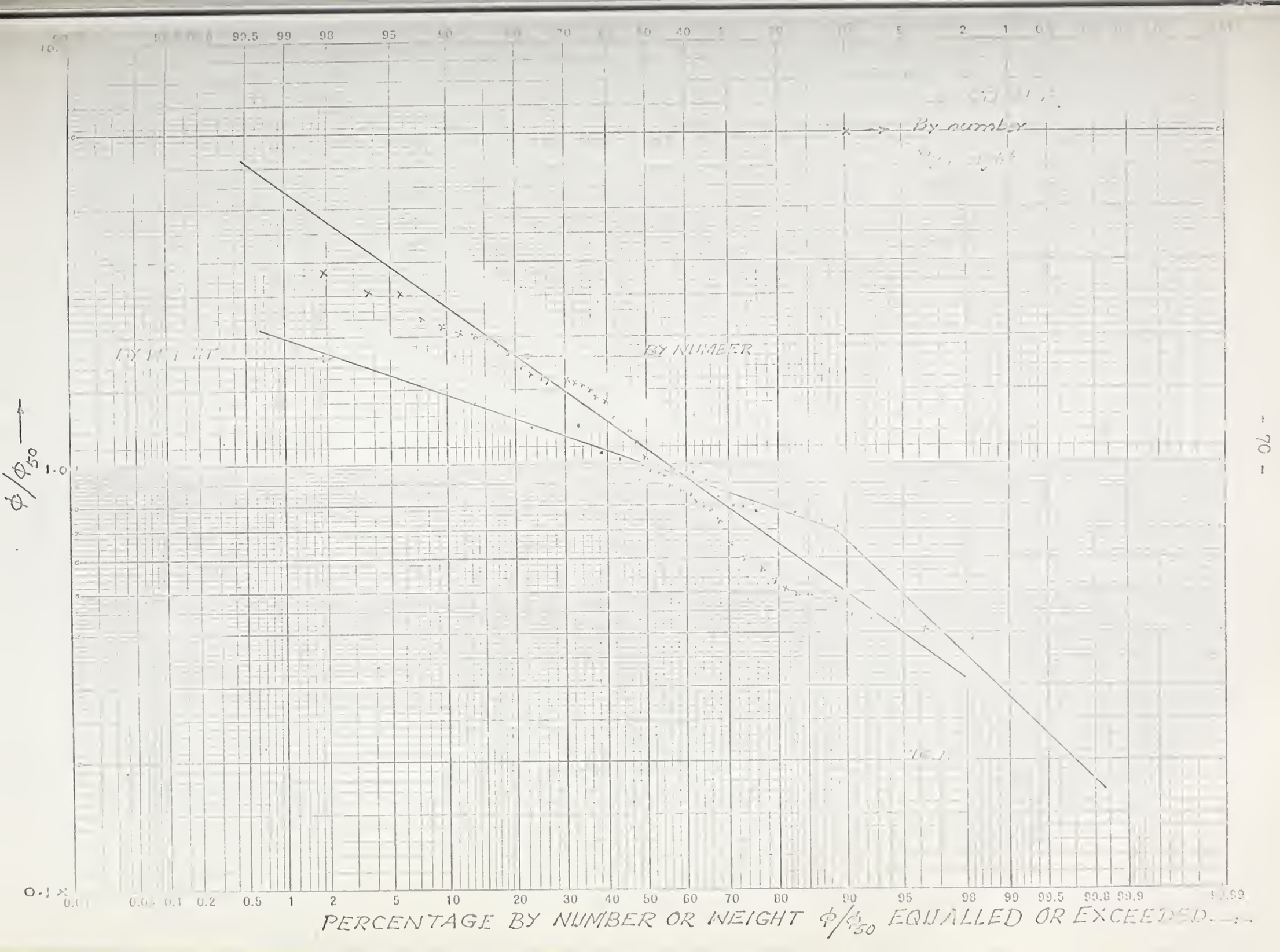
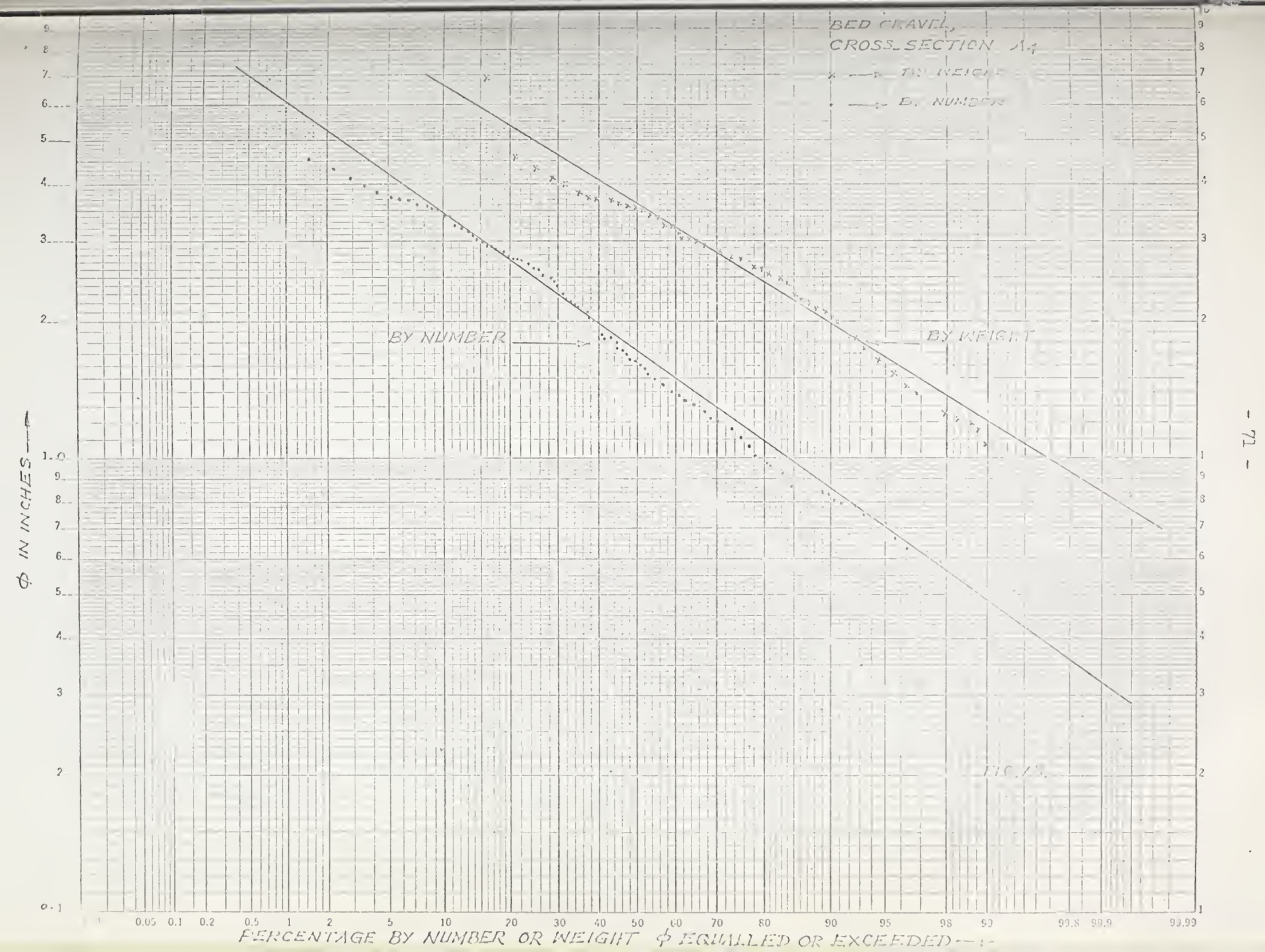

RED GRAVEL, CROSS SECTION A.
α
α/1·50
α IN INCHES
α/α50
PERCENTAGE BY WEIGHT α OR α/α50 EQUALLED OR EXCEEDED
0·01 0·05 0·1 0·2 0·5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99·8 99·9 99·99

FIG. 15


RAVEL,
CROSS-SECTION A 3
PERCENTAGE BY WEIGHT
PERCENTAGE BY NUMBER
BY NUMBER
BY WEIGHT
FIG. 16.
φ IN INCHES.
PERCENTAGE THE φ EQUALLED OR EXCEEDED
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
0.1
0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.95


By number
BY NUMBER
BY WEIGHT
ϕ/ϕ_{50}
1.0
0.1
99.5 99 98 95
70
40
5 2 1
0.01 0.02 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9
PERCENTAGE BY NUMBER OR WEIGHT ϕ/ϕ_{50} EQUALLED OR EXCEEDED.


BED GRAVEL,
CROSS-SECTION A-A
× —— BY WEIGHT
• —— BY NUMBER
BY NUMBER
BY WEIGHT
FIG. 13.
φ IN INCHES
PERCENTAGE BY NUMBER OR WEIGHT φ EQUALLED OR EXCEEDED
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
0.1
0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99

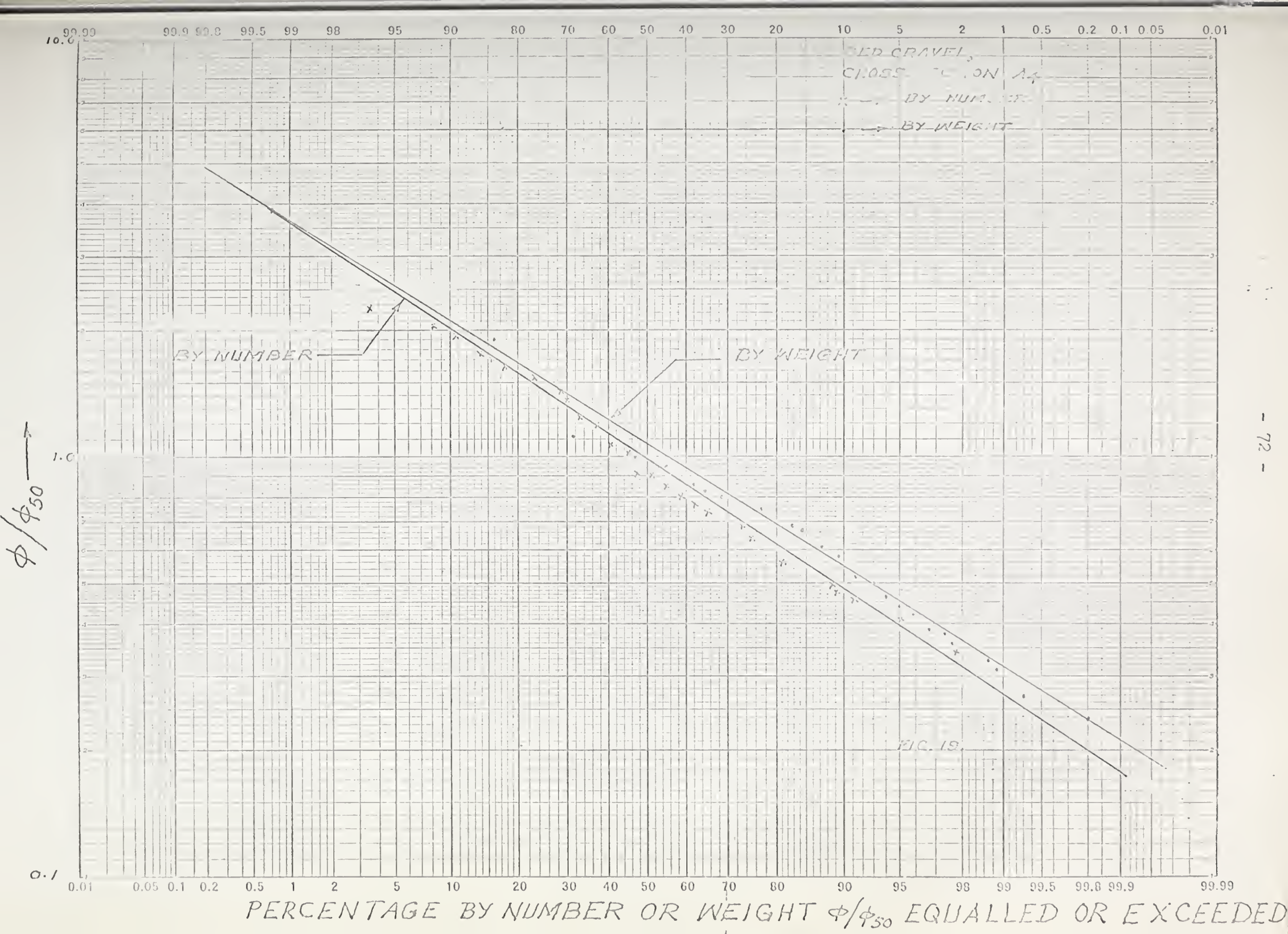

99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
10.0
1.0
0.1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
BY NUMBER
BY WEIGHT
Φ/Φ50
PERCENTAGE BY NUMBER OR WEIGHT Φ/Φ50 EQUALLED OR EXCEEDED

FIG. 19.

- 72 -

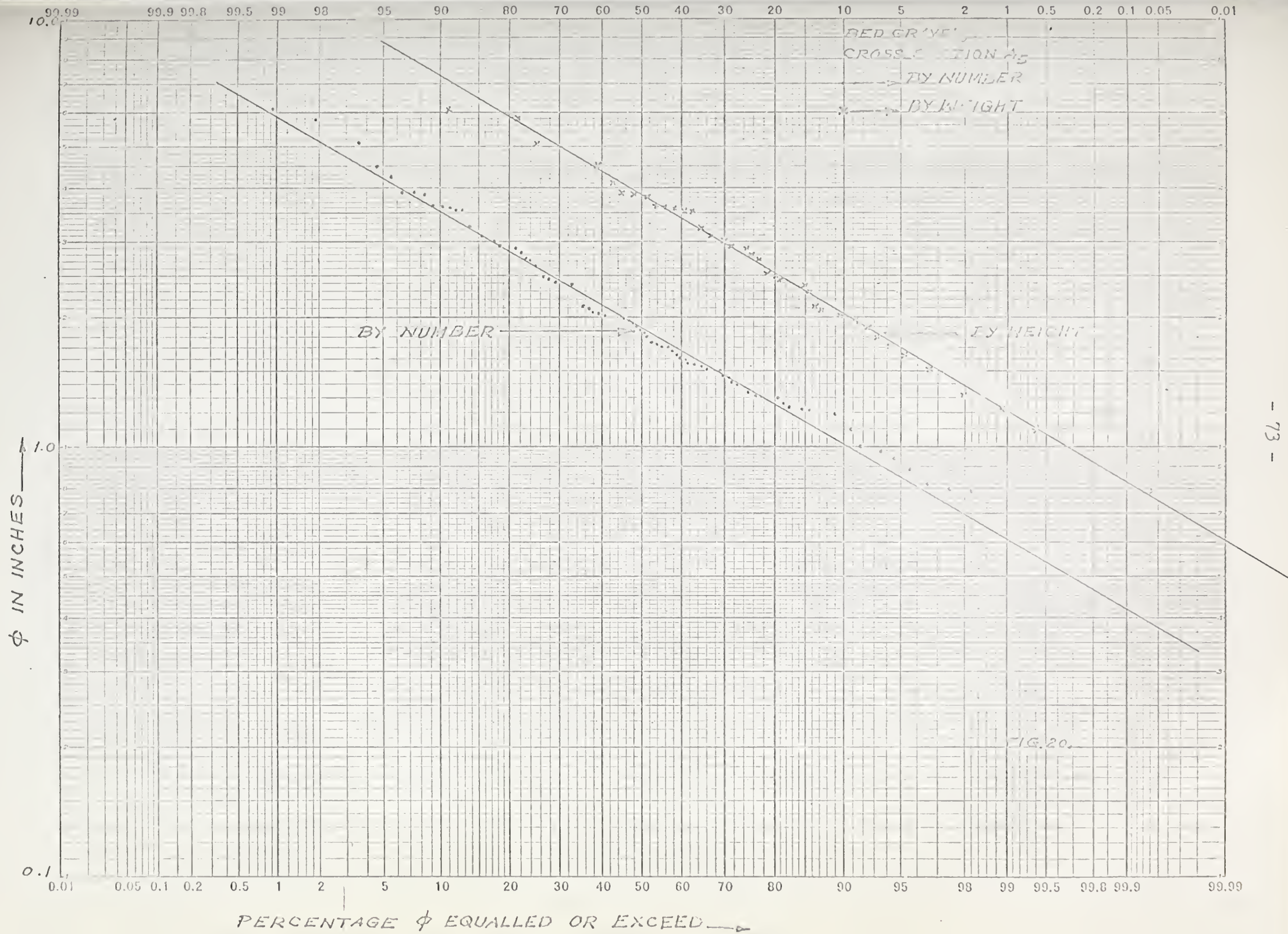

99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
10.0
1.0
0.1
BED GRAVEL CROSS-SECTION A5
BY NUMBER
BY WEIGHT
BY NUMBER
BY WEIGHT
φ IN INCHES
PERCENTAGE φ EQUALLED OR EXCEED
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99

FIG. 20.

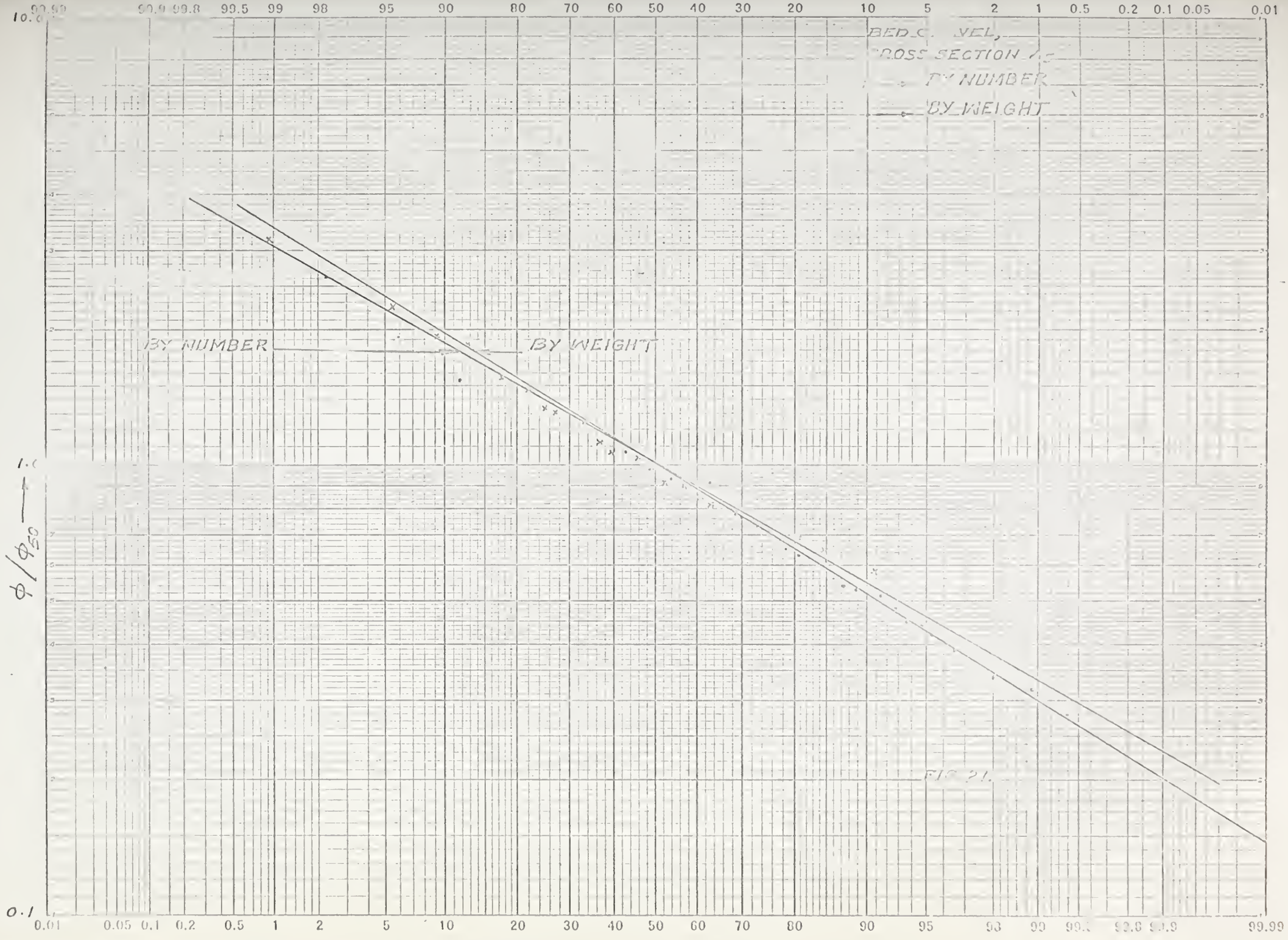
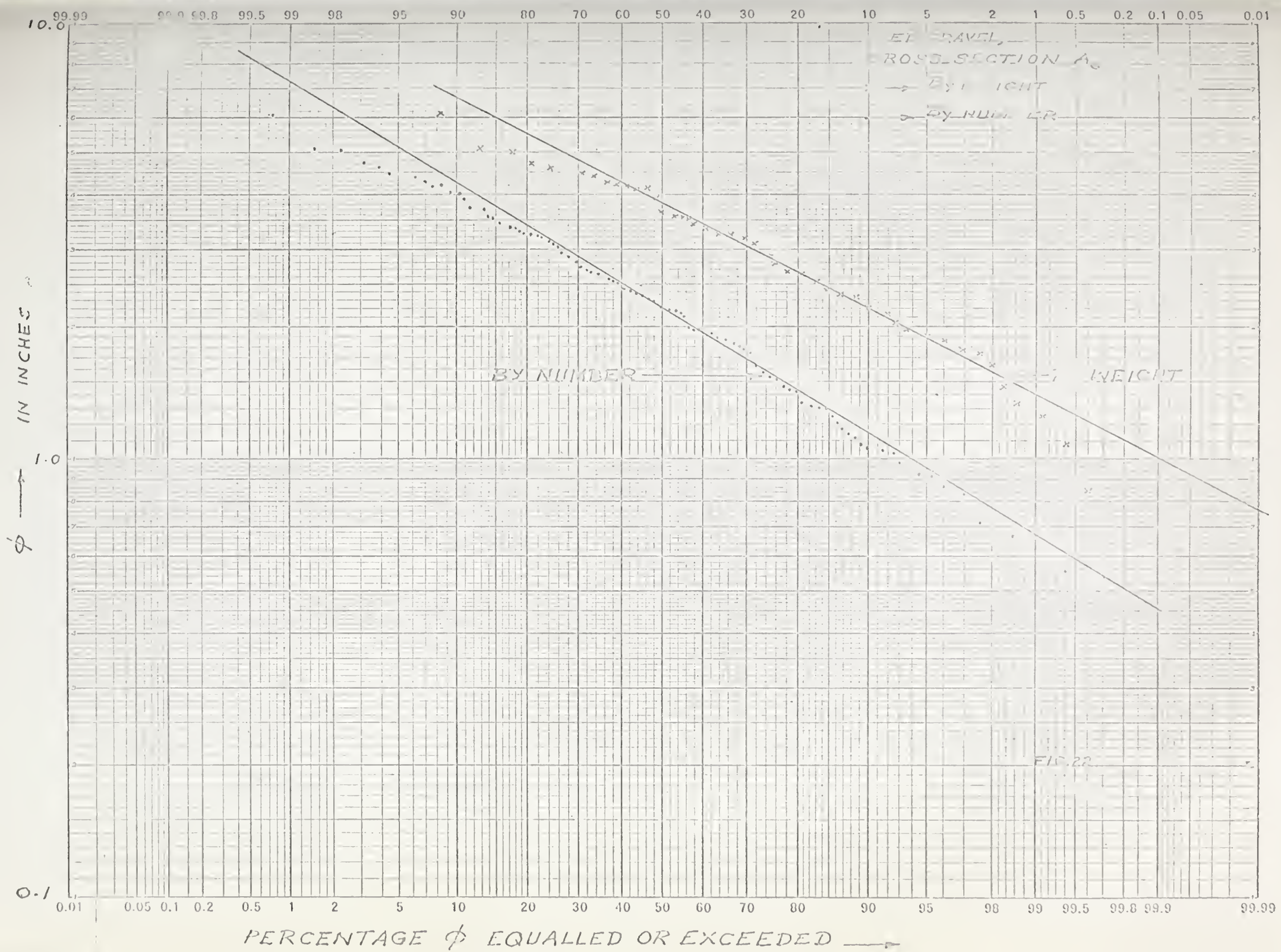
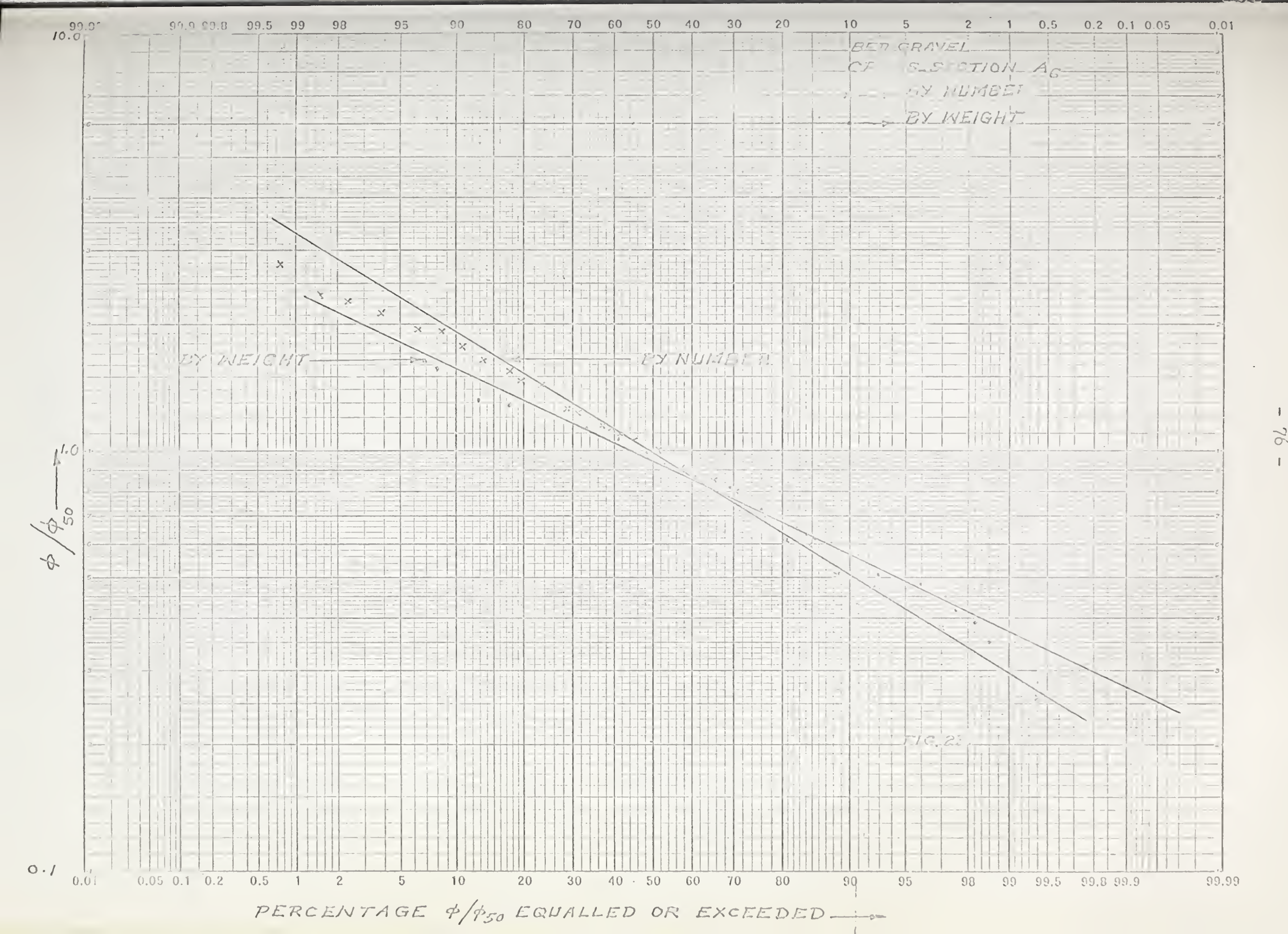
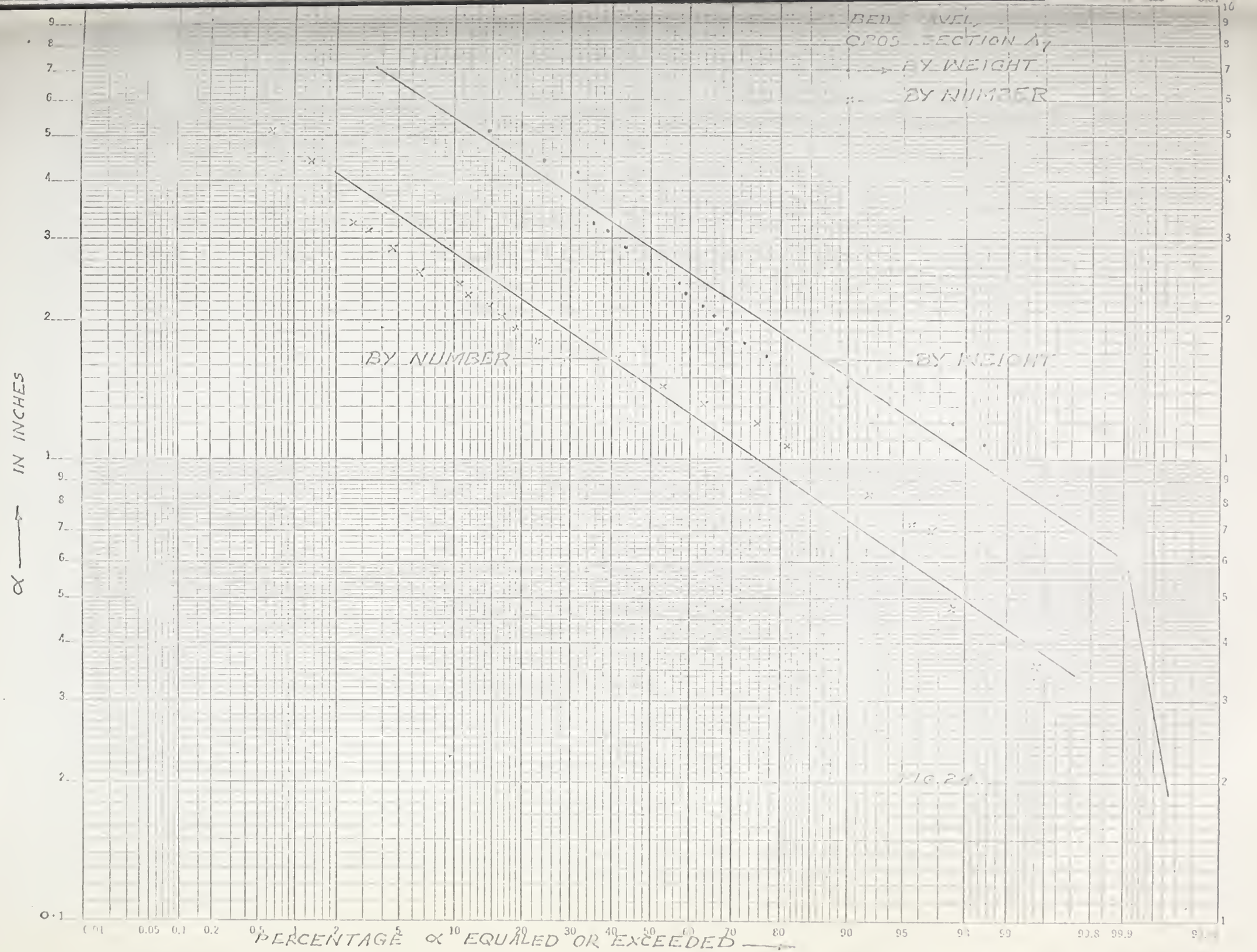
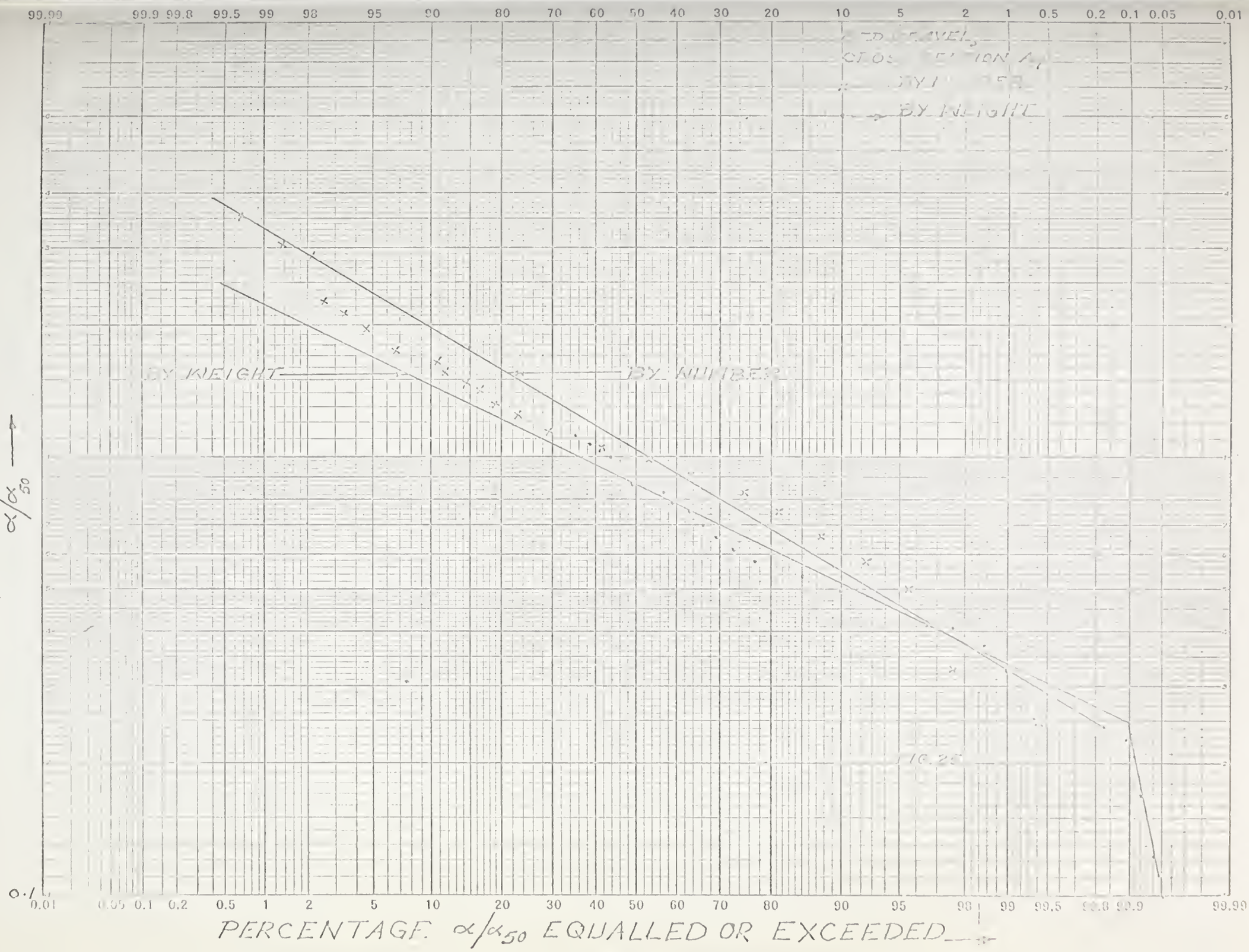

BED C. VEL. CROSS SECTION
BY NUMBER
BY WEIGHT
BY NUMBER
BY WEIGHT
φ/φ50
PERCENTAGE φ/φ50 EQUALLED OR EXCEEDED
99.99

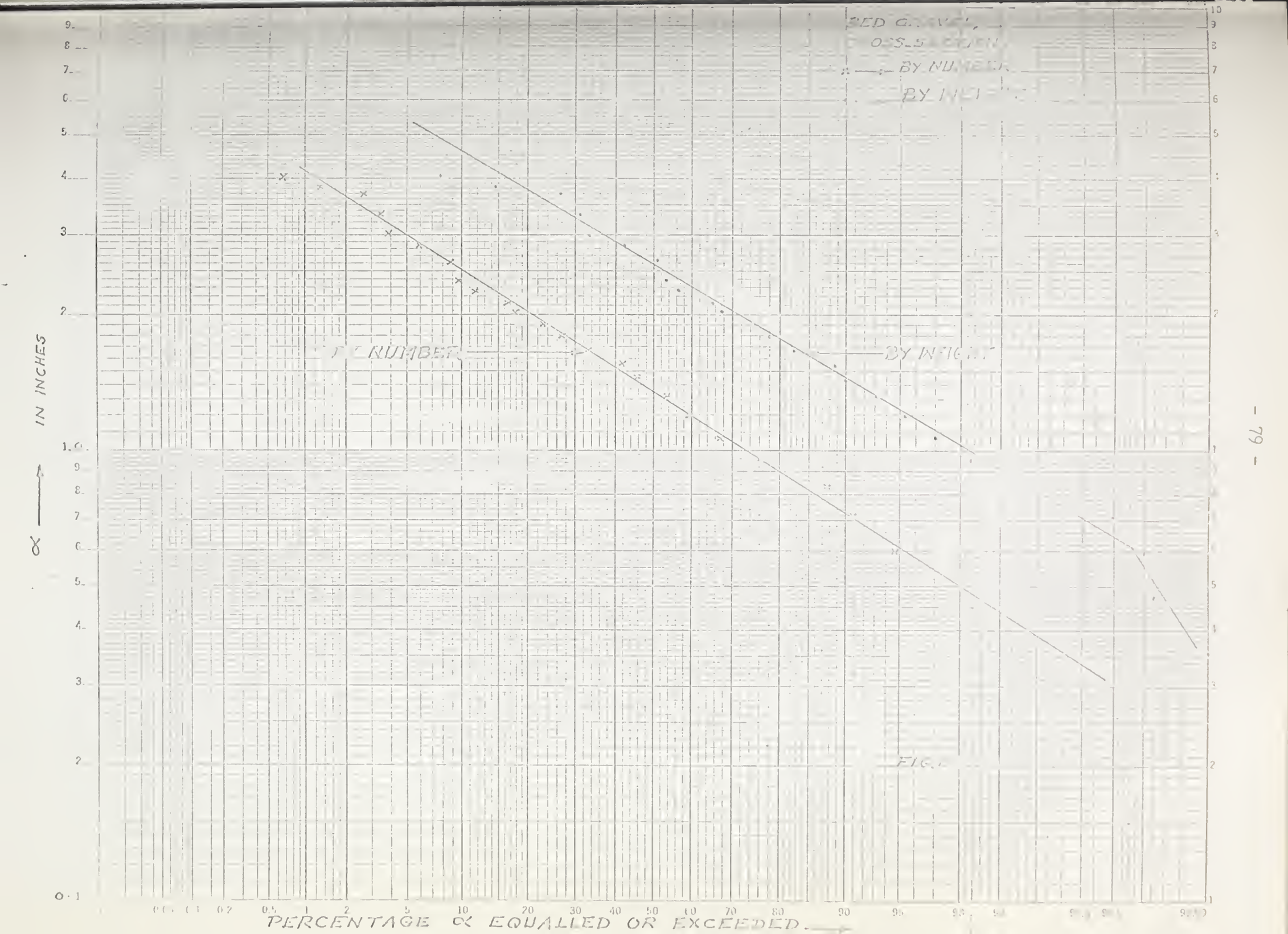
FIG 21.

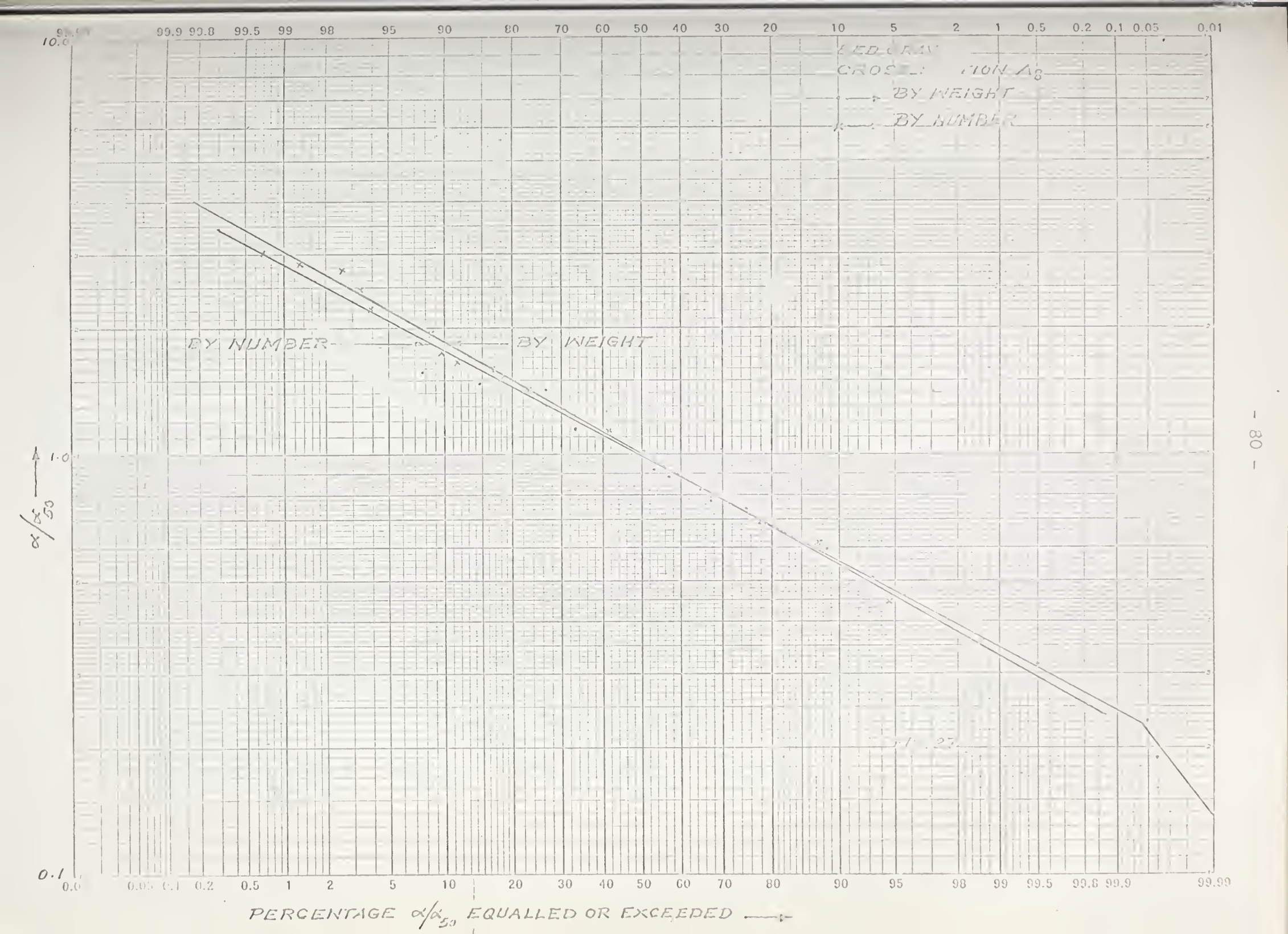

99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
10.0
1.0
0.1
φ — IN INCHES
EL GRAVEL, ROSS SECTION A
BY WEIGHT
BY NUMBER
BY NUMBER
BY WEIGHT
FIG. 22
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
PERCENTAGE φ EQUALLED OR EXCEEDED —


BED GRAVEL
CROSS-SECTION A6
BY NUMBER
BY WEIGHT
BY WEIGHT
BY NUMBER
FIG. 21
10.0
1.0
0.1
φ/φ50
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
PERCENTAGE φ/φ50 EQUALLED OR EXCEEDED


BED LEVEL
CROSS SECTION AT
BY WEIGHT
BY NUMBER
BY NUMBER
BY WEIGHT
α IN INCHES
PERCENTAGE α EQUALLED OR EXCEEDED
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
FIG. 24.


99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
BY WEIGHT
BY NUMBER
α/α50
0.1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
PERCENTAGE α/α50 EQUALLED OR EXCEEDED


RED GRAVEL
OBSERVATION
BY NUMBER
BY WEIGHT
BY NUMBER
BY WEIGHT
FIG.
x IN INCHES
PERCENTAGE x EQUALLED OR EXCEEDED.


99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
10.0
1.0
0.1
0.0 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
BY NUMBER
BY WEIGHT
BY NUMBER
BY WEIGHT
α/α50
PERCENTAGE α/α50 EQUALLED OR EXCEEDED

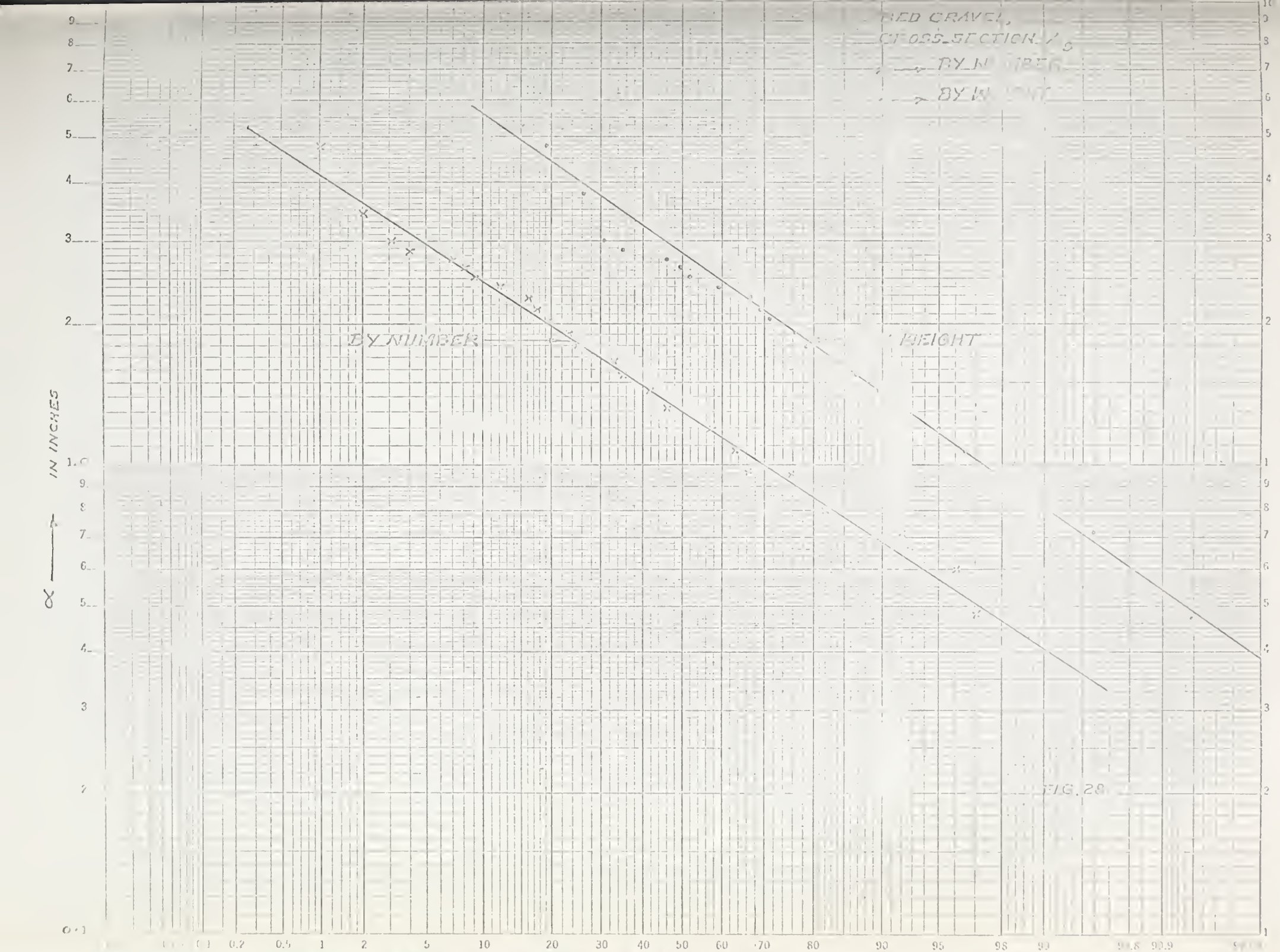
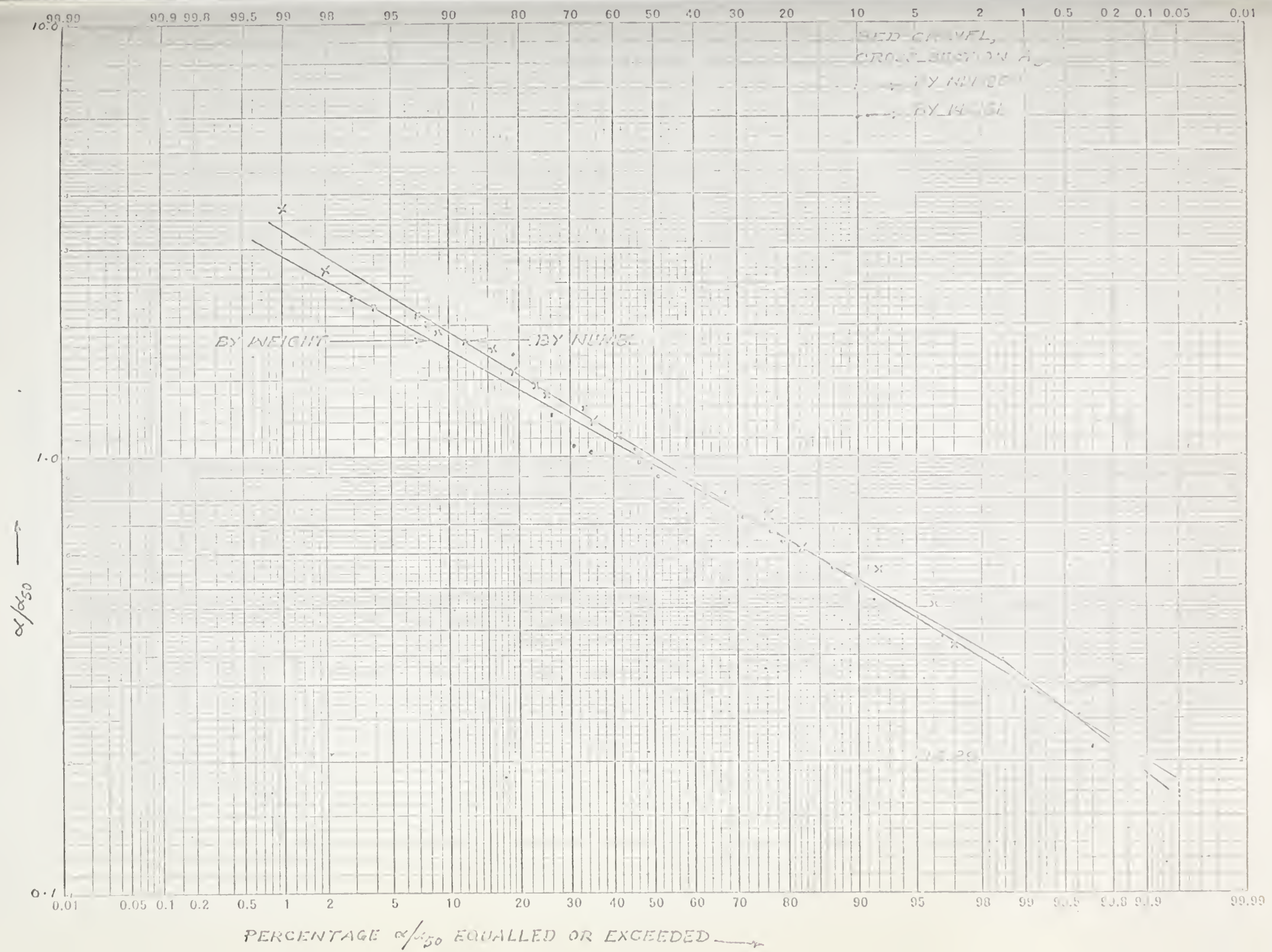
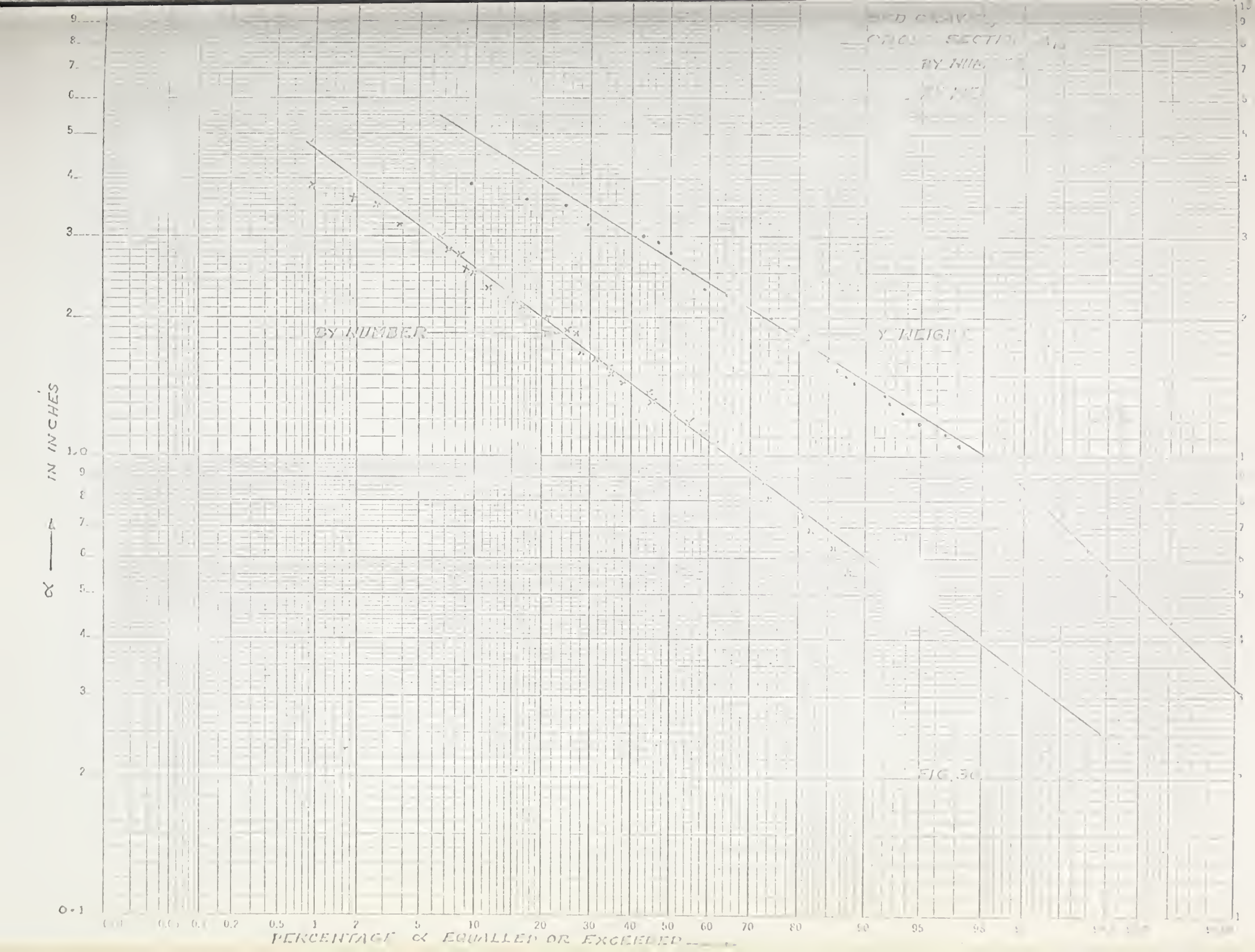

BY NUMBER
BY WEIGHT
IN INCHES
PERCENTAGE OF EQUALLED OR EXCEEDED

FIG. 28


99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
10.0
1.0
0.1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
BY WEIGHT
BY NUMBER
α/α50
PERCENTAGE α/α50 EQUALLED OR EXCEEDED


BY NUMBER
Y WEIGHT
α — IN INCHES
PERCENTAGE α EQUALLED OR EXCEEDED
FIG. 30

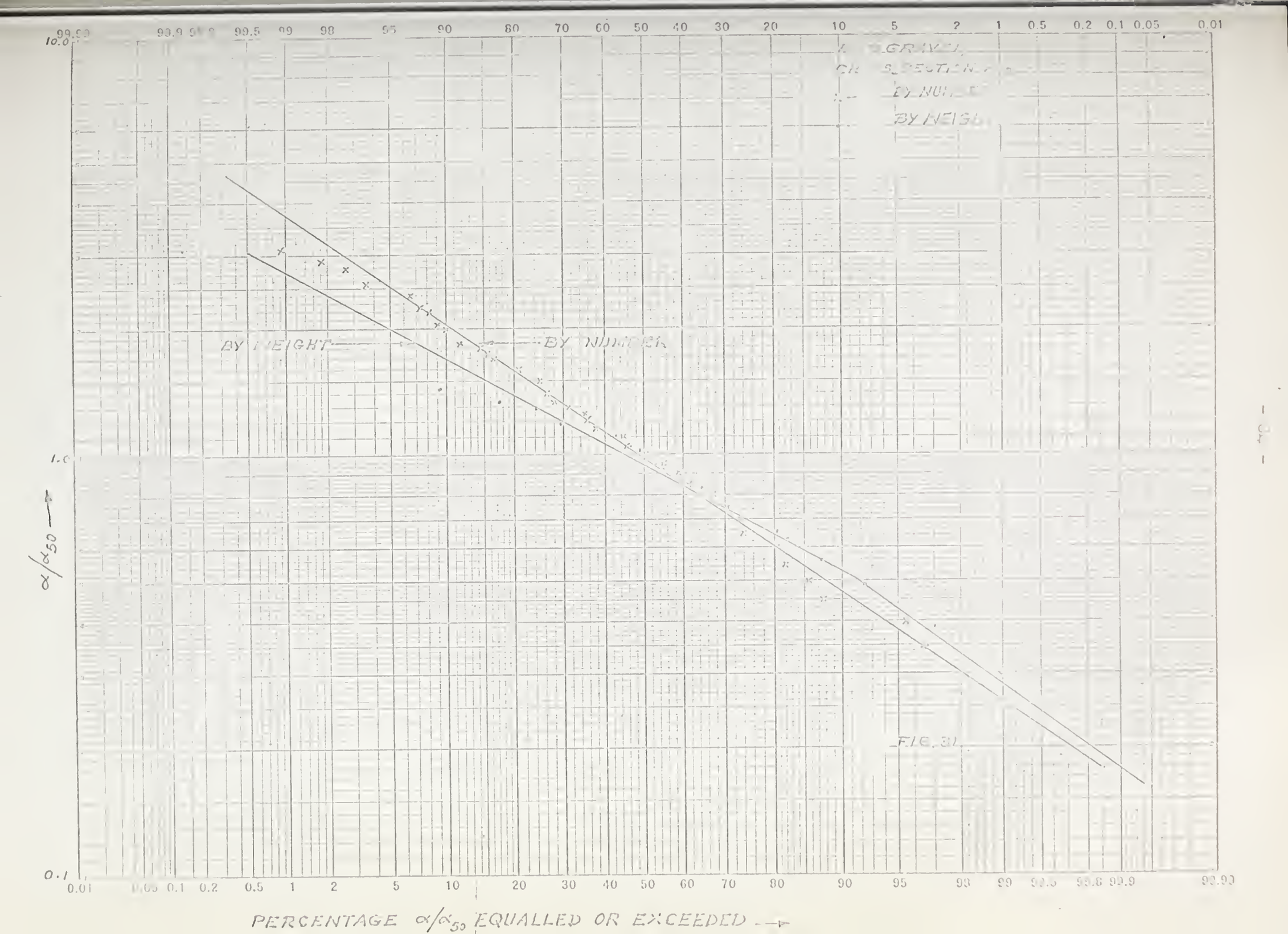
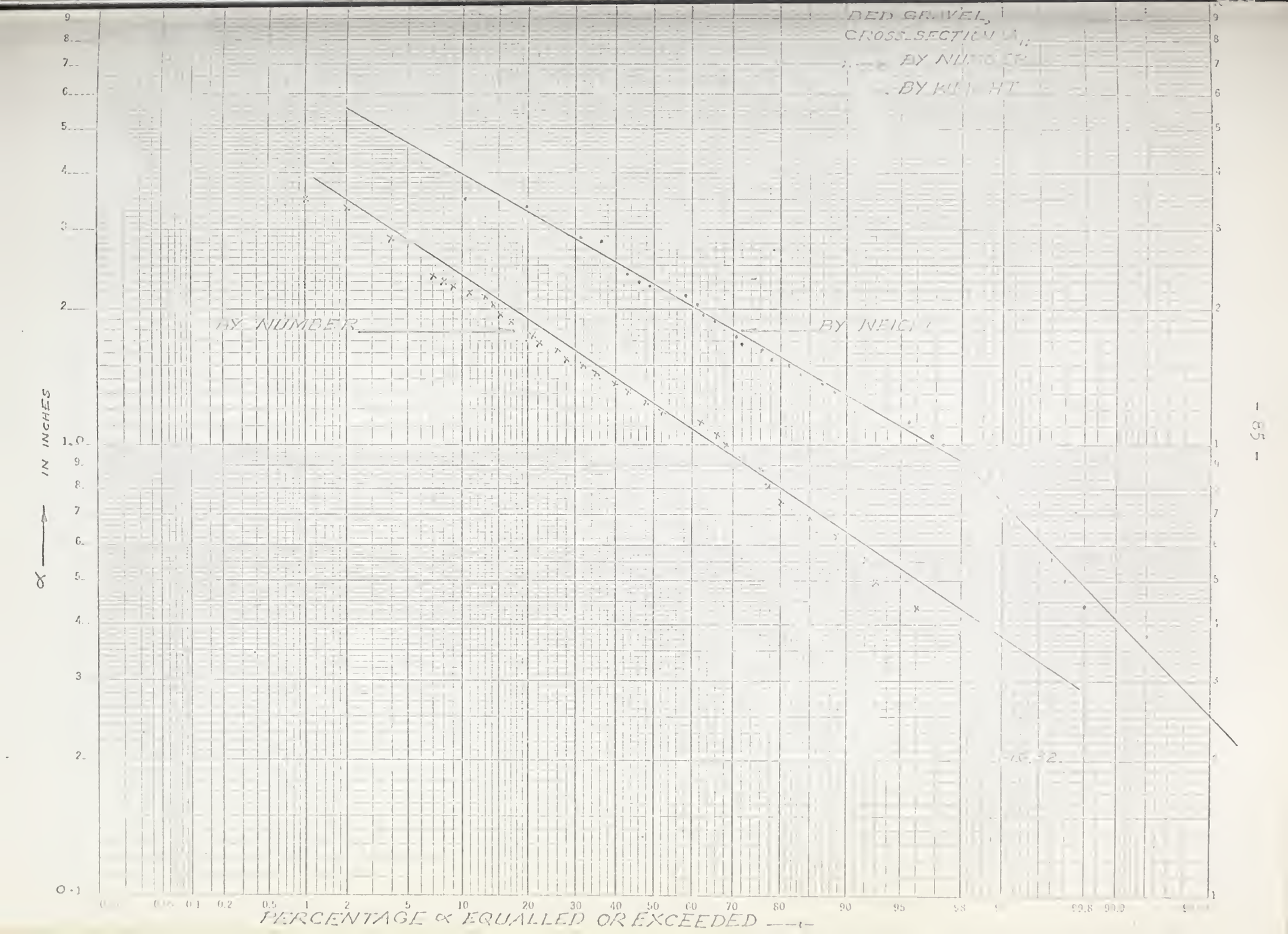

99.99
99.9
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
10.0
1.0
0.1
BY WEIGHT
BY NUMBER
α/α50
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
PERCENTAGE α/α50 EQUALLED OR EXCEEDED

FIG. 31.


BED GRAVEL,
CROSS-SECTION A,
BY NUMBER
BY WEIGHT
BY NUMBER
BY WEIGHT
FIG. 12.
x — IN INCHES
PERCENTAGE x EQUALLED OR EXCEEDED
0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99.8 99.9

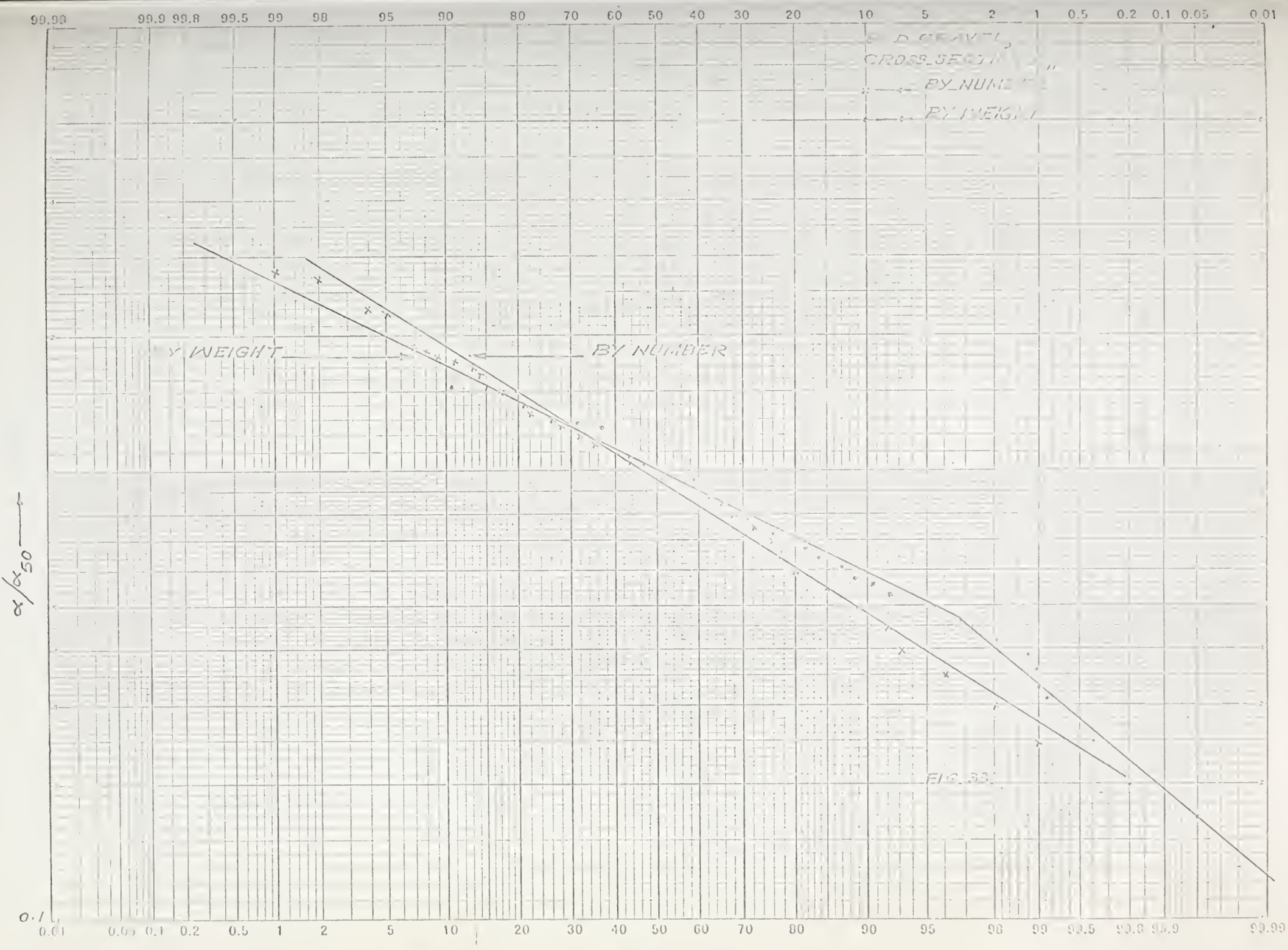

99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
BY WEIGHT
BY NUMBER
0.1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
PERCENTAGE

FIG. 33.

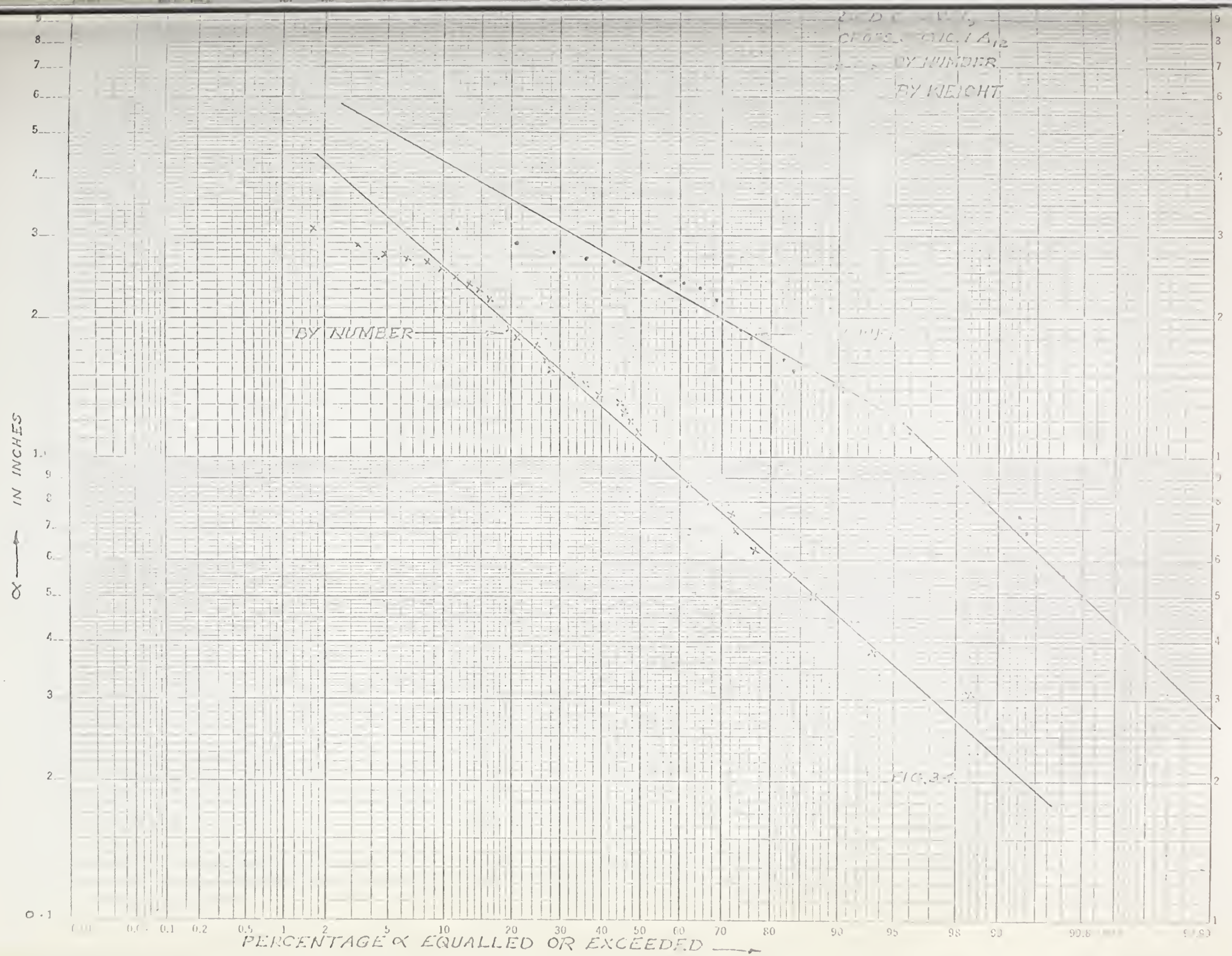
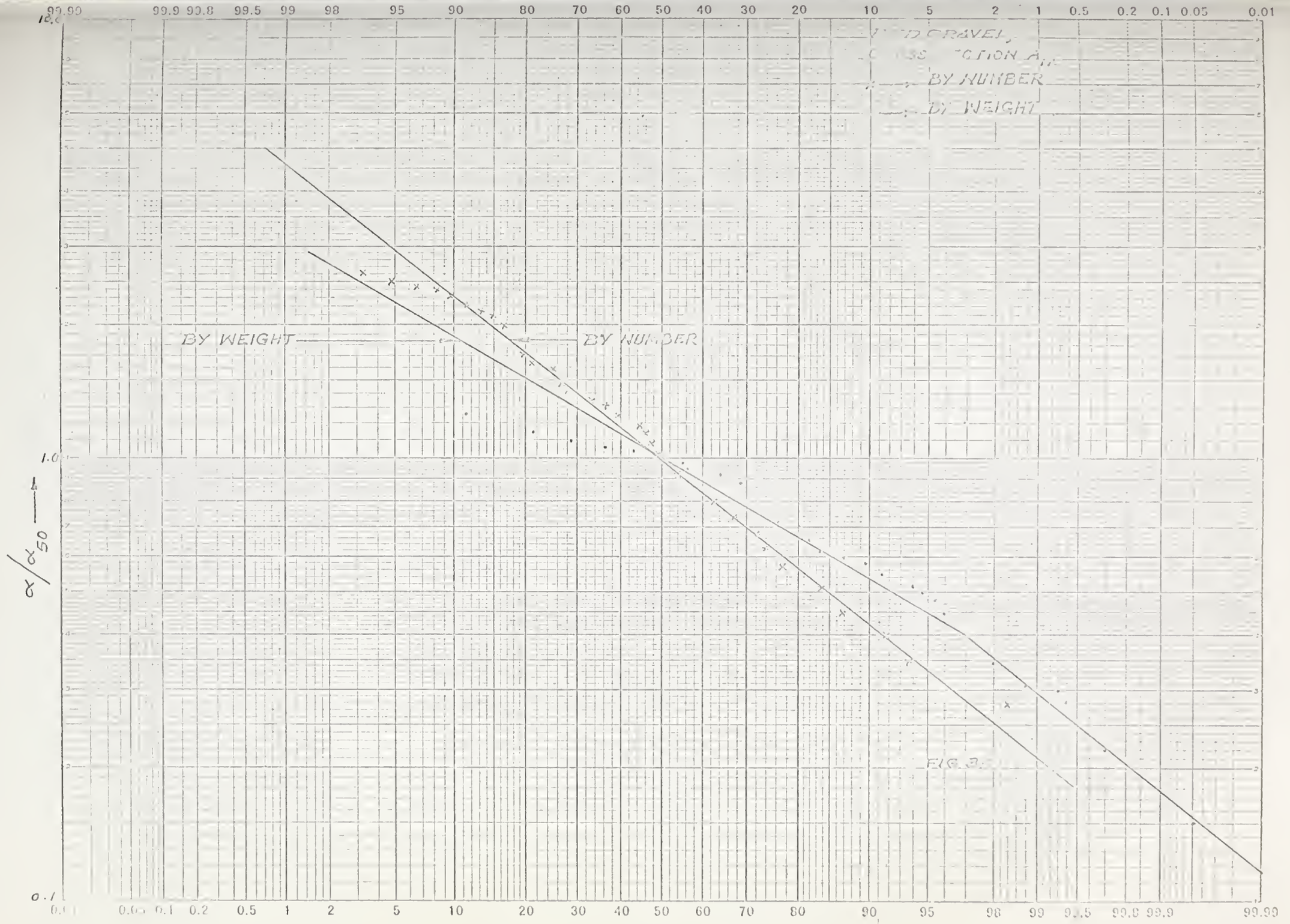

BY NUMBER
BY WEIGHT
x IN INCHES
PERCENTAGE x EQUALLED OR EXCEEDED
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8

FIG. 34.



α/α_{50}

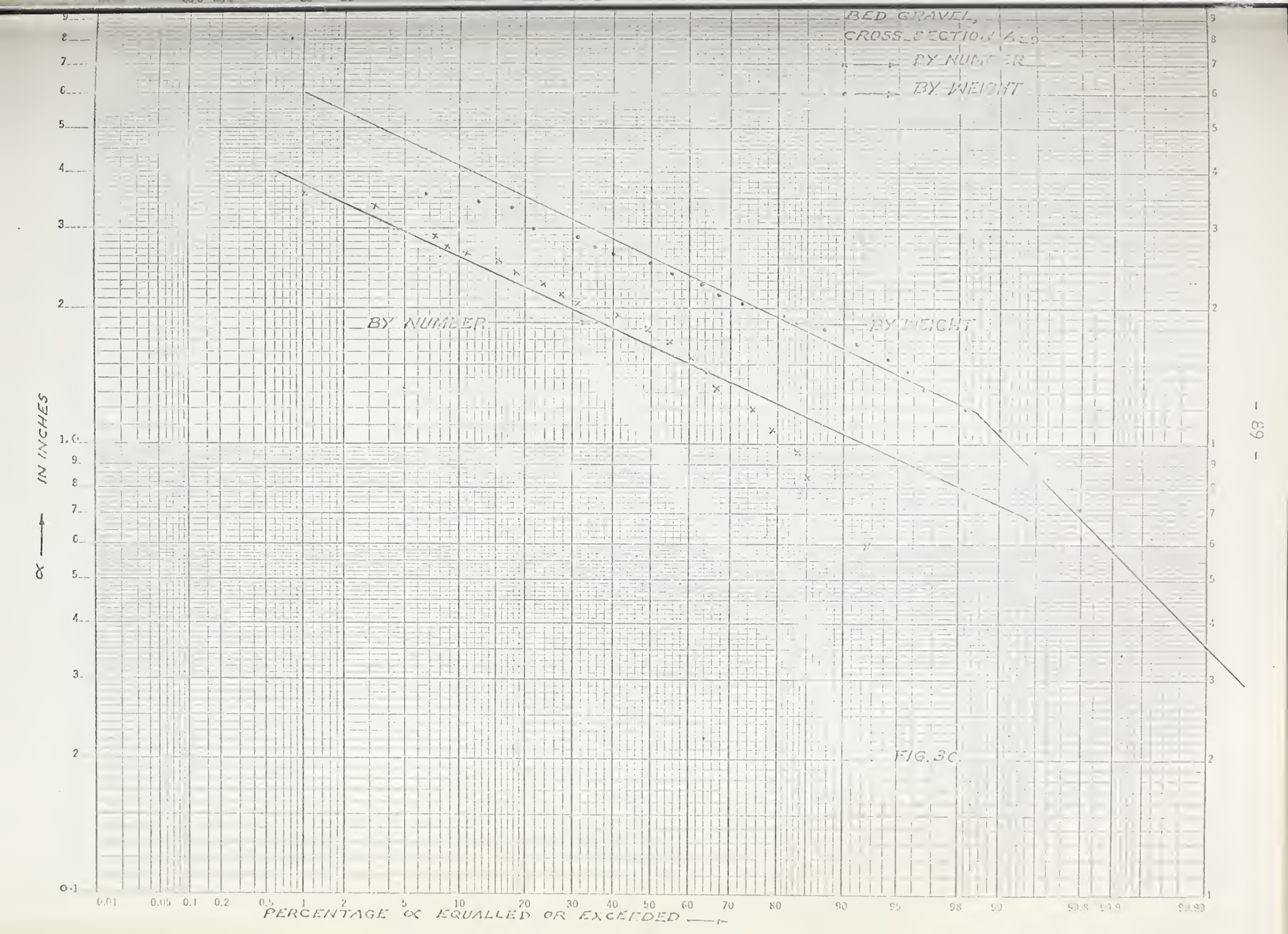
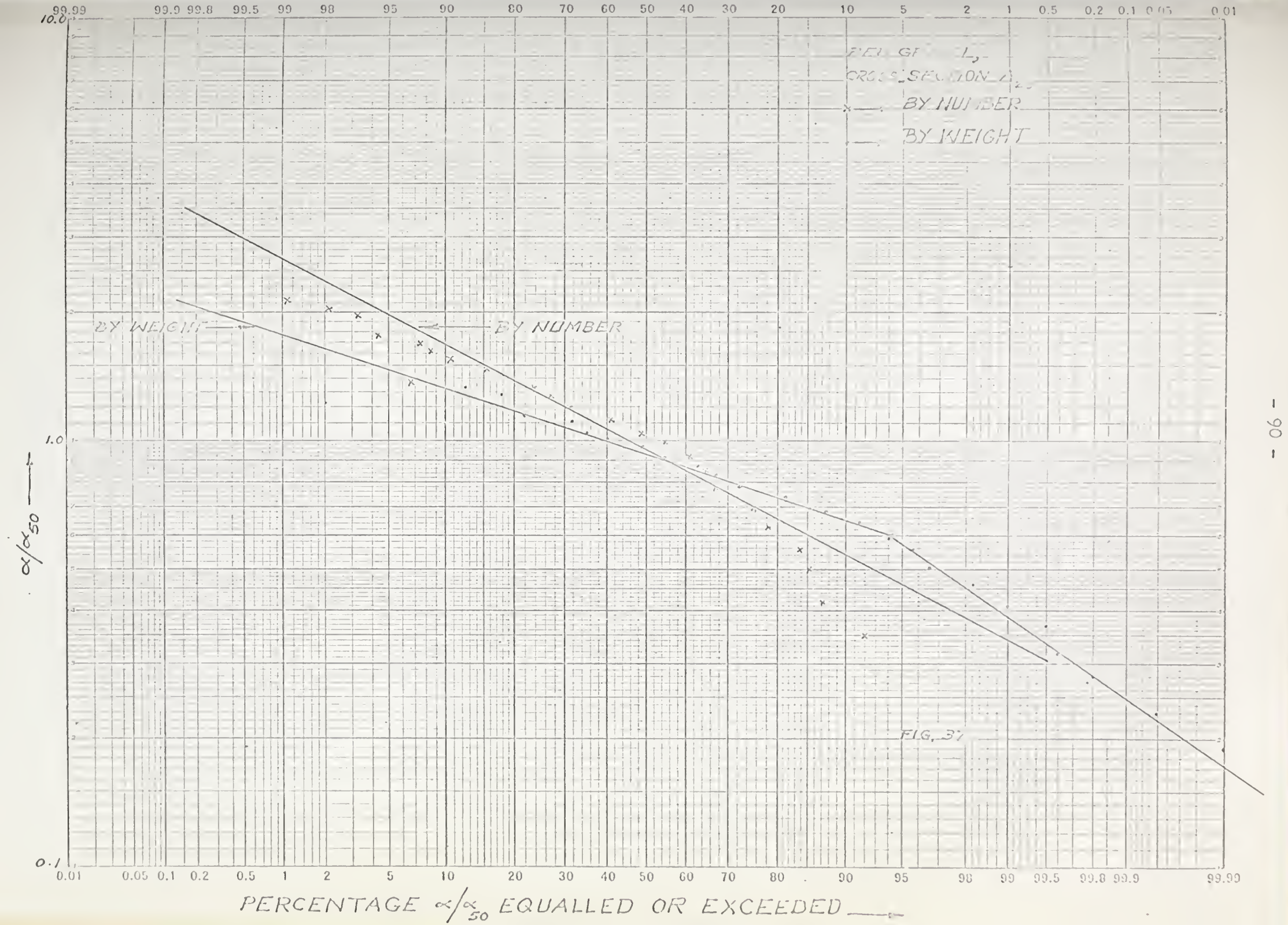

BED GRAVEL,
CROSS-SECTION A-B
BY NUMBER
BY WEIGHT
BY NUMBER
BY WEIGHT
x — IN INCHES
PERCENTAGE x EQUALLED OR EXCEEDED
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
0.1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. 3C.


99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
10.0
1.0
0.1
BY WEIGHT
BY NUMBER
BY NUMBER
BY WEIGHT
FIG. 37
α/α50
PERCENTAGE α/α50 EQUALLED OR EXCEEDED
- 90 -

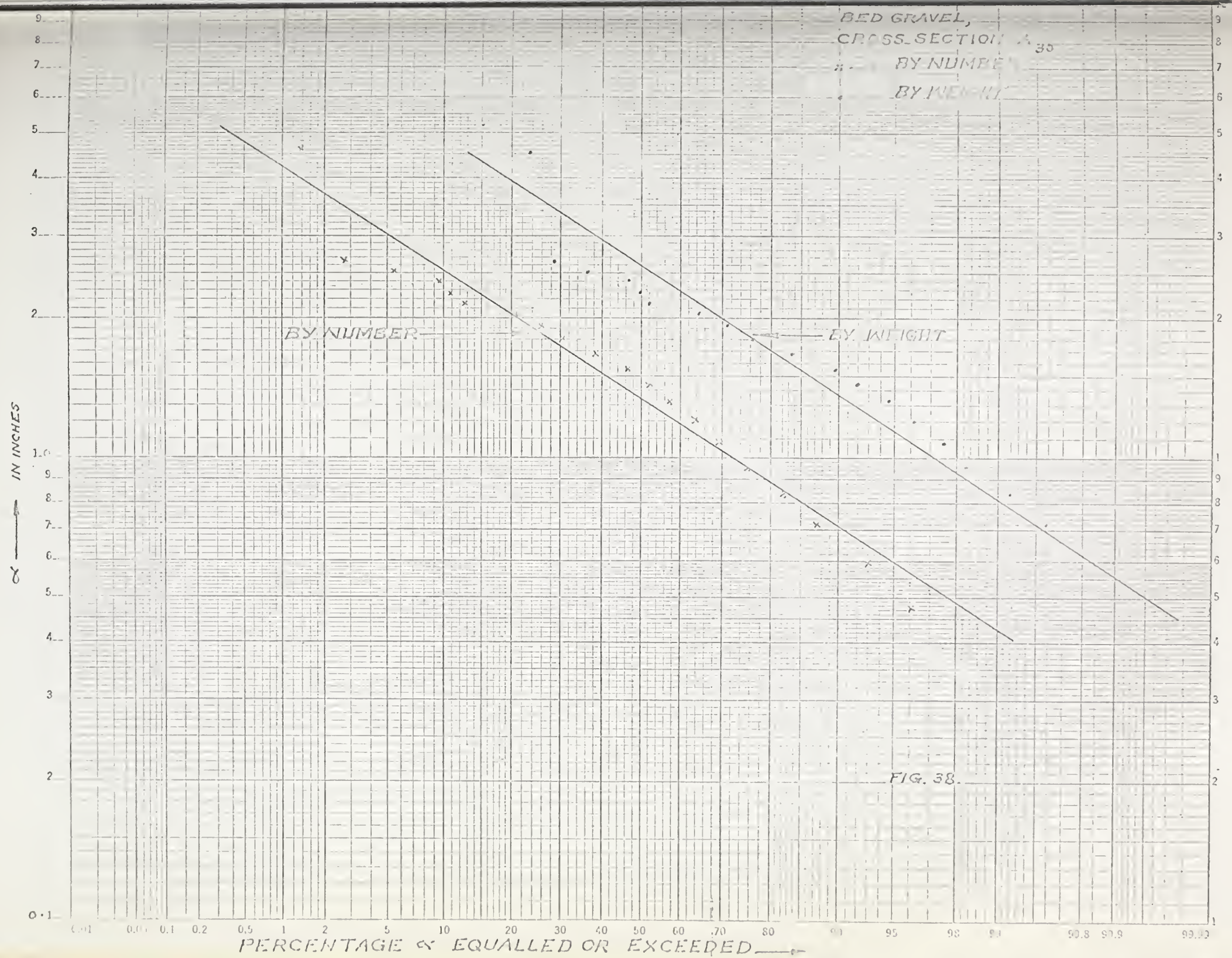

BED GRAVEL,
CROSS-SECTION A 35
BY NUMBER
BY WEIGHT
BY NUMBER
BY WEIGHT
x — IN INCHES
PERCENTAGE x EQUALLED OR EXCEEDED
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
0·1
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. 38.

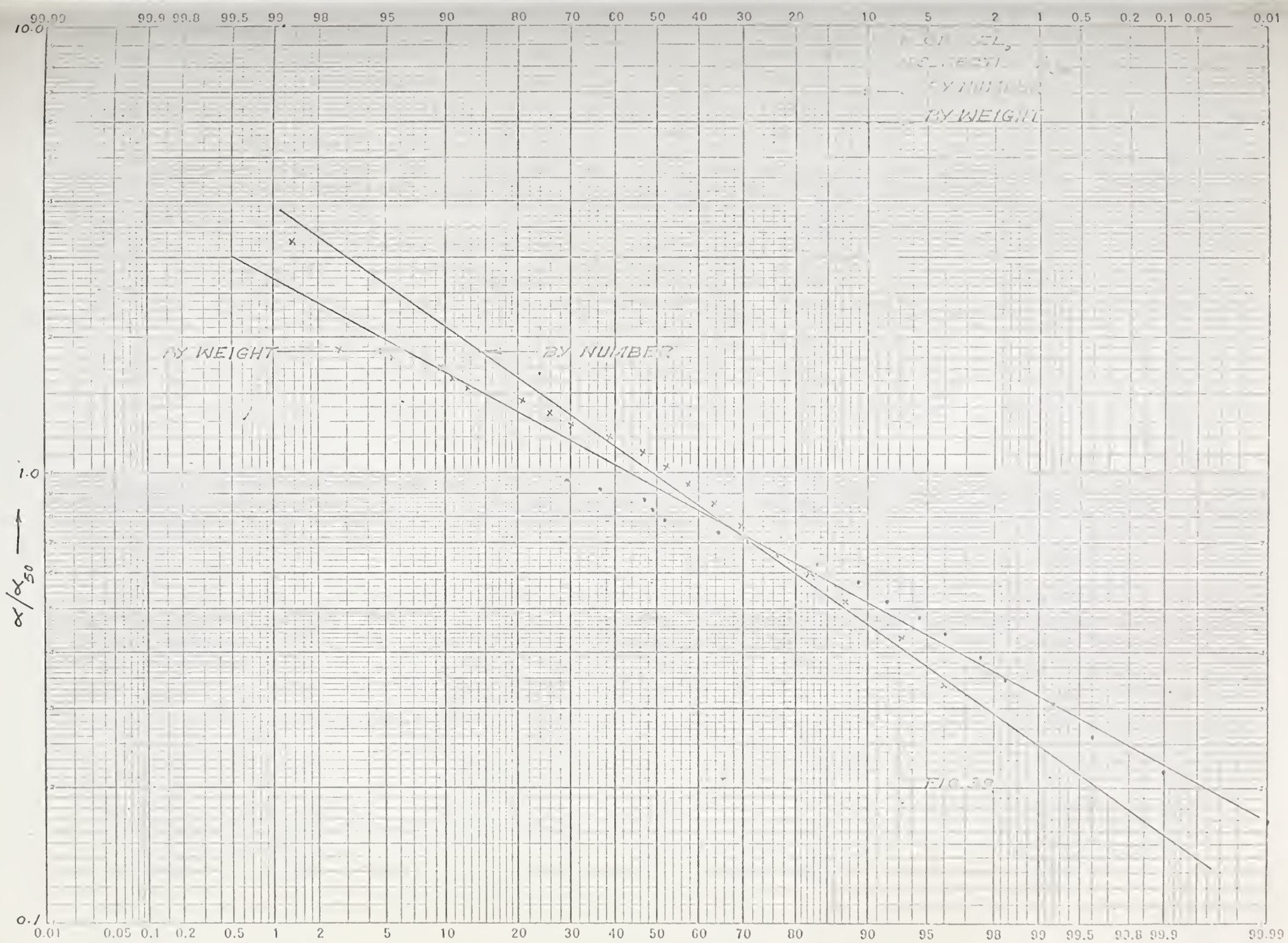

99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
10.0
1.0
0.1
α/α50
BY WEIGHT
BY NUMBER
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
PERCENTAGE α/α50 EQUALLED OR EXCEEDED

FIG. 39

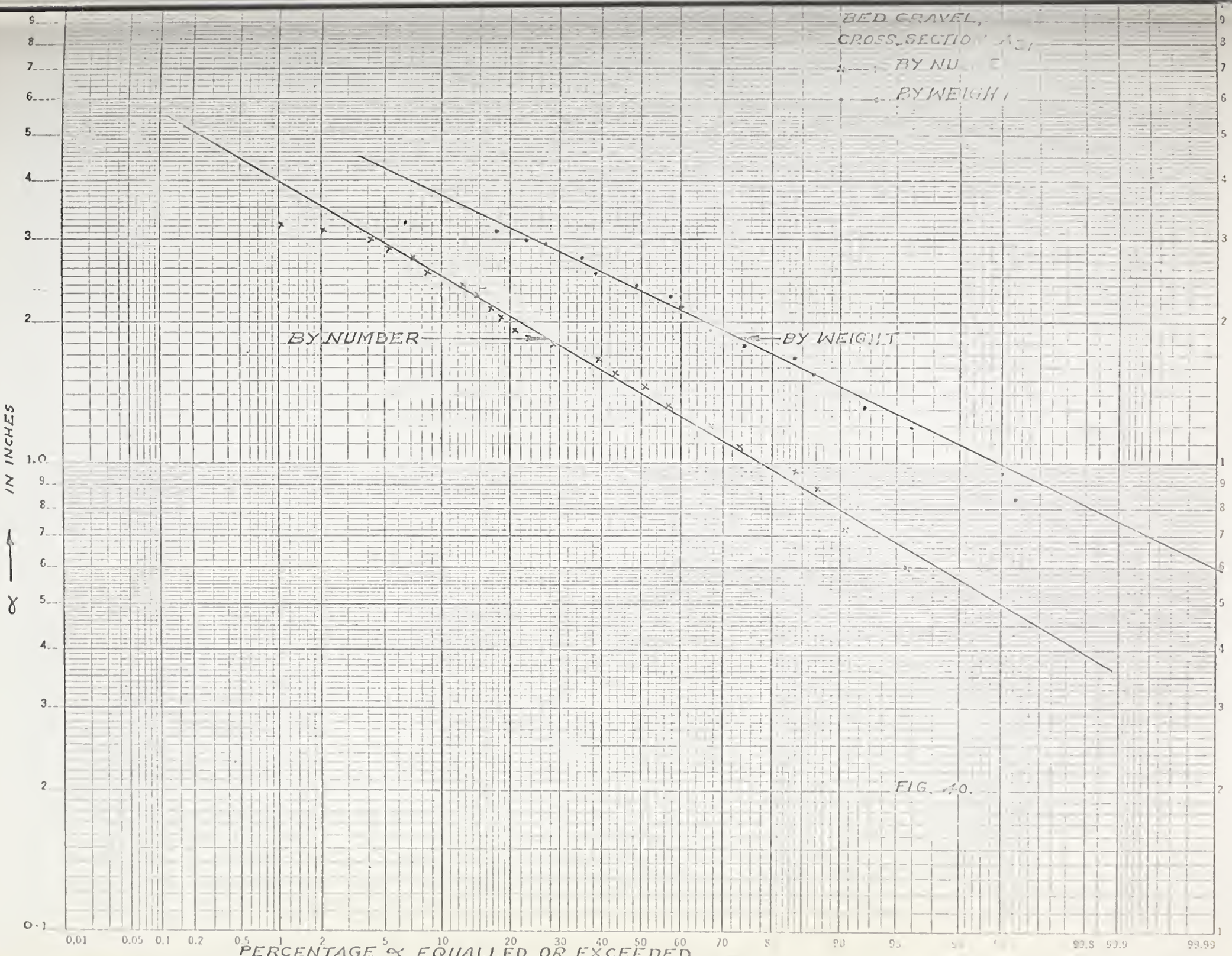
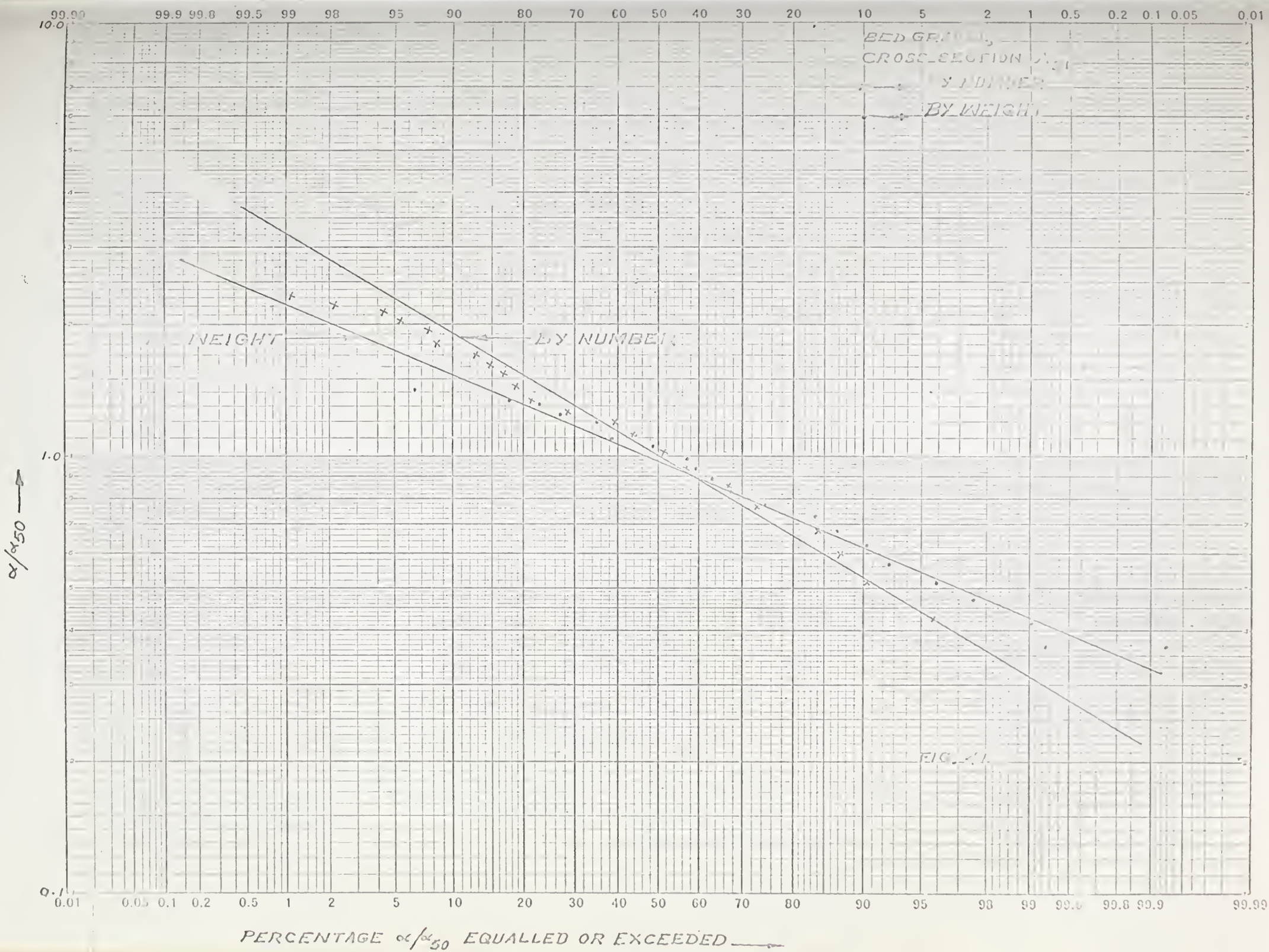

BED GRAVEL,
CROSS-SECTION A-1
BY NUMBER
BY WEIGHT
BY NUMBER
BY WEIGHT
x IN INCHES
PERCENTAGE x EQUALLED OR EXCEEDED
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

FIG. 40.


99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
10.0
1.0
0.1
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
BED GR
CROSS-SECTION
BY NUMBER
BY WEIGHT
WEIGHT
BY NUMBER
FIG. 11.
α/α50
PERCENTAGE α/α50 EQUALLED OR EXCEEDED

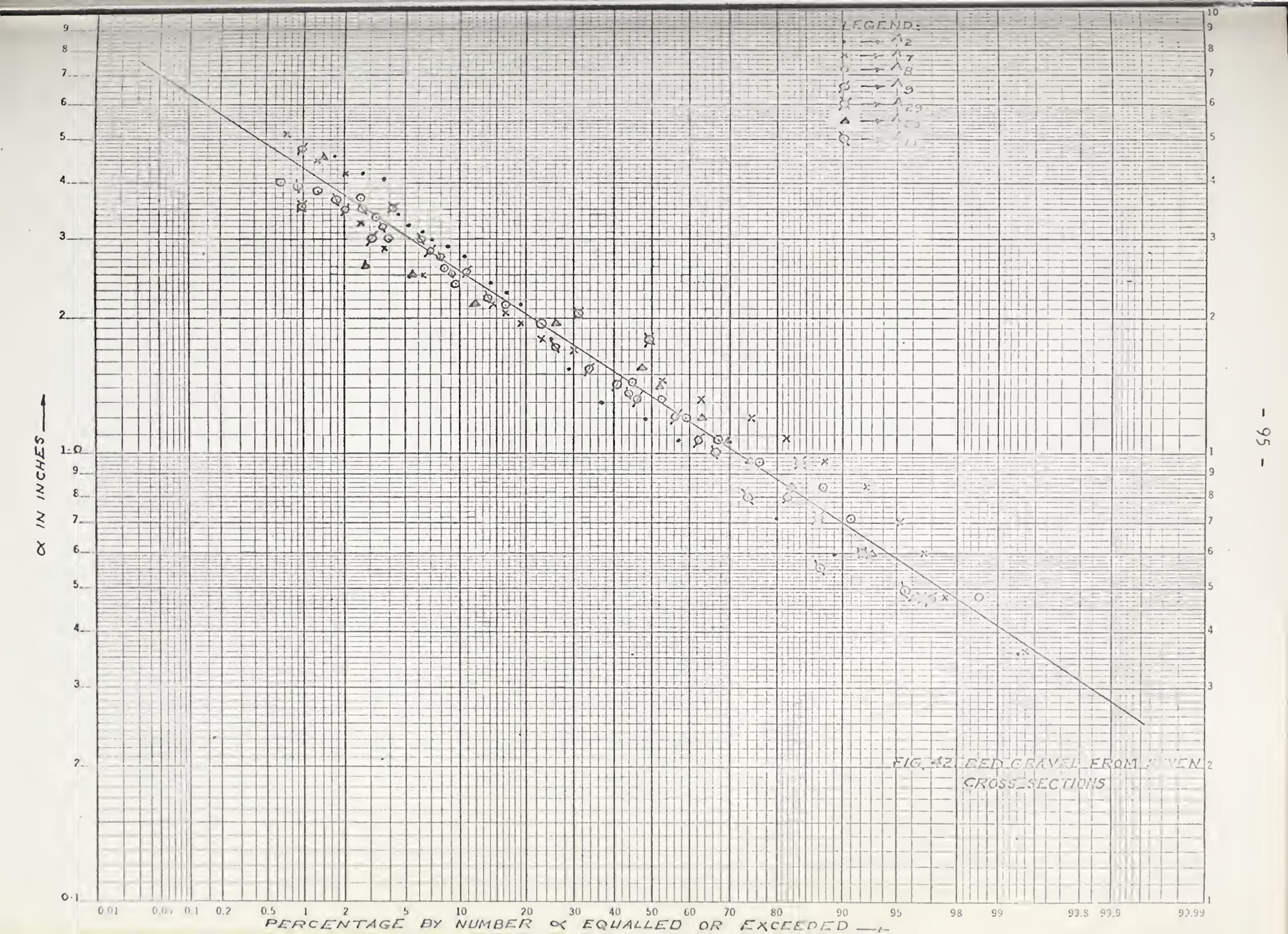


FIG. 42 ...DED GRAVEL FROM ...VEN CROSS-SECTIONS

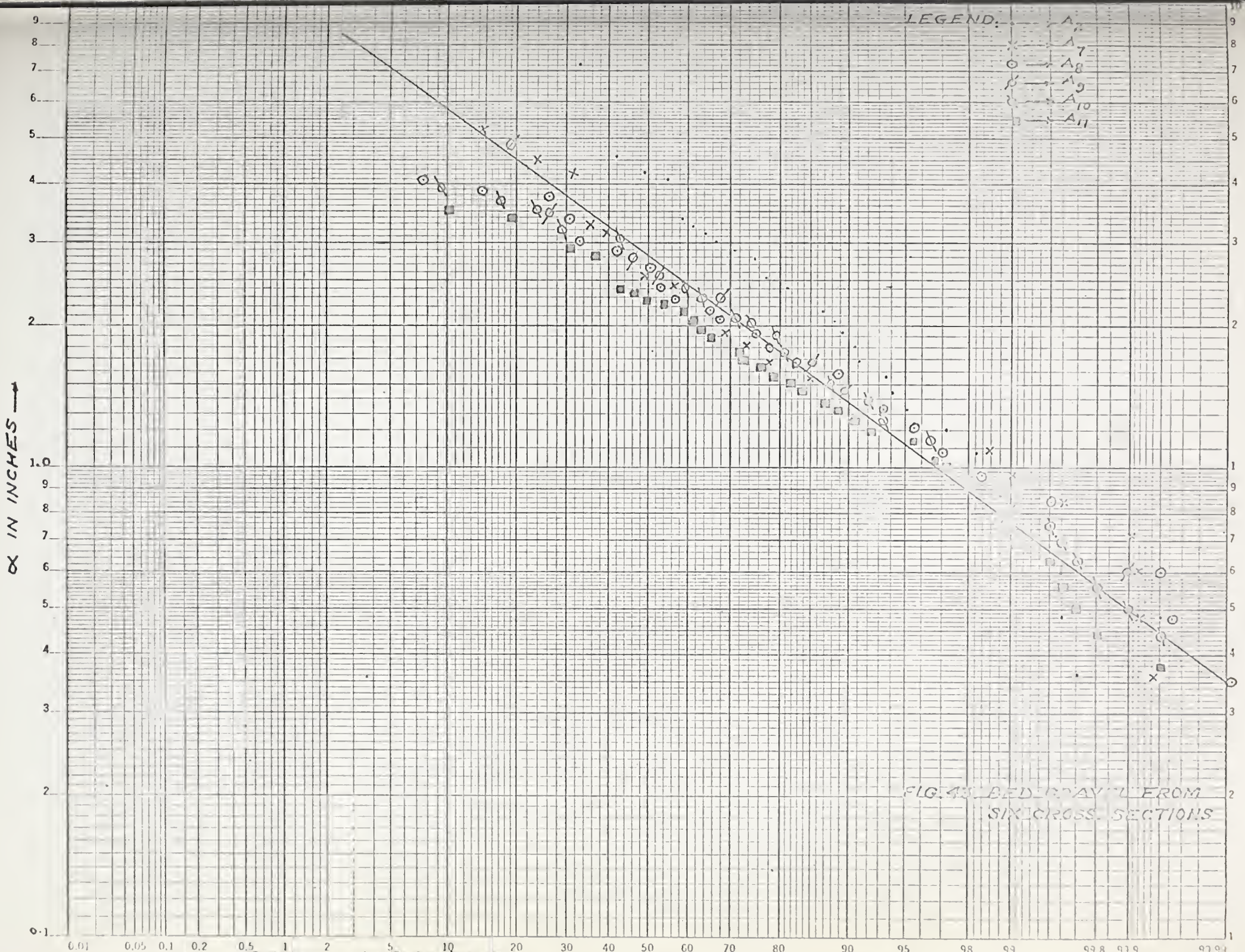


FIG. 43. BED-PAVEMENT FROM SIX CROSS-SECTIONS

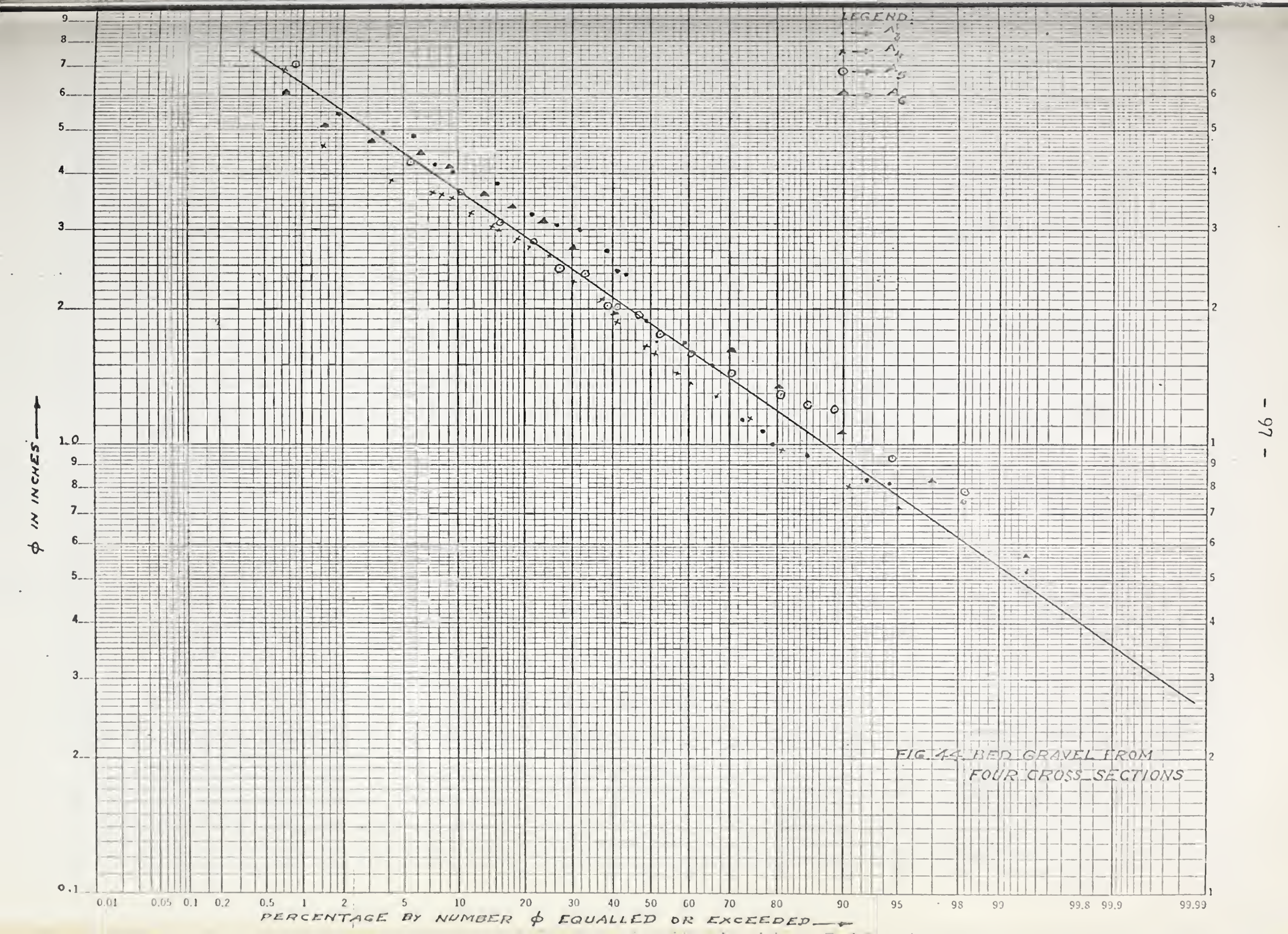


FIG. 44 BED GRAVEL FROM FOUR CROSS-SECTIONS

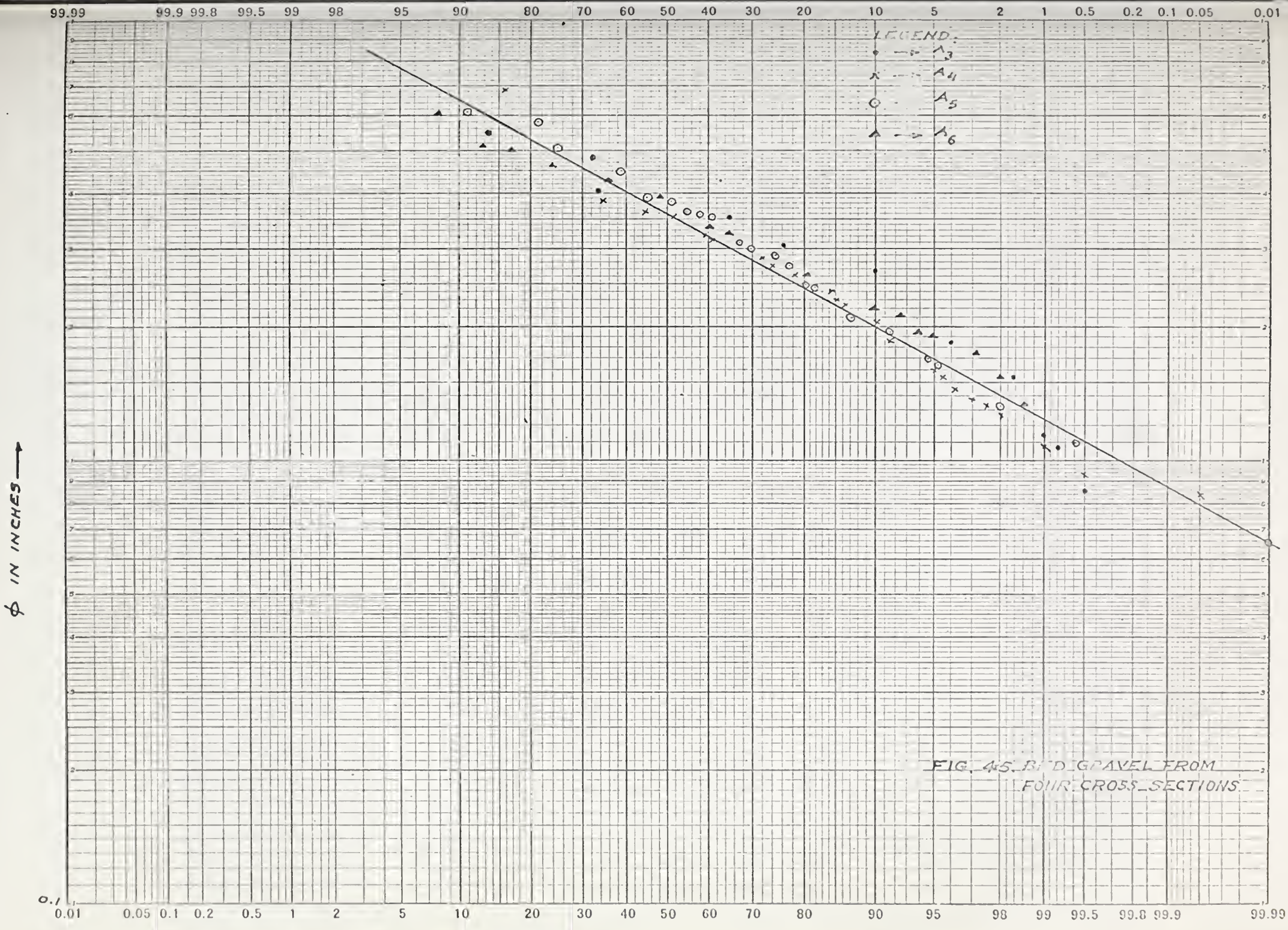


FIG. 45. BIRD GRAVEL FROM FOUR CROSS-SECTIONS.

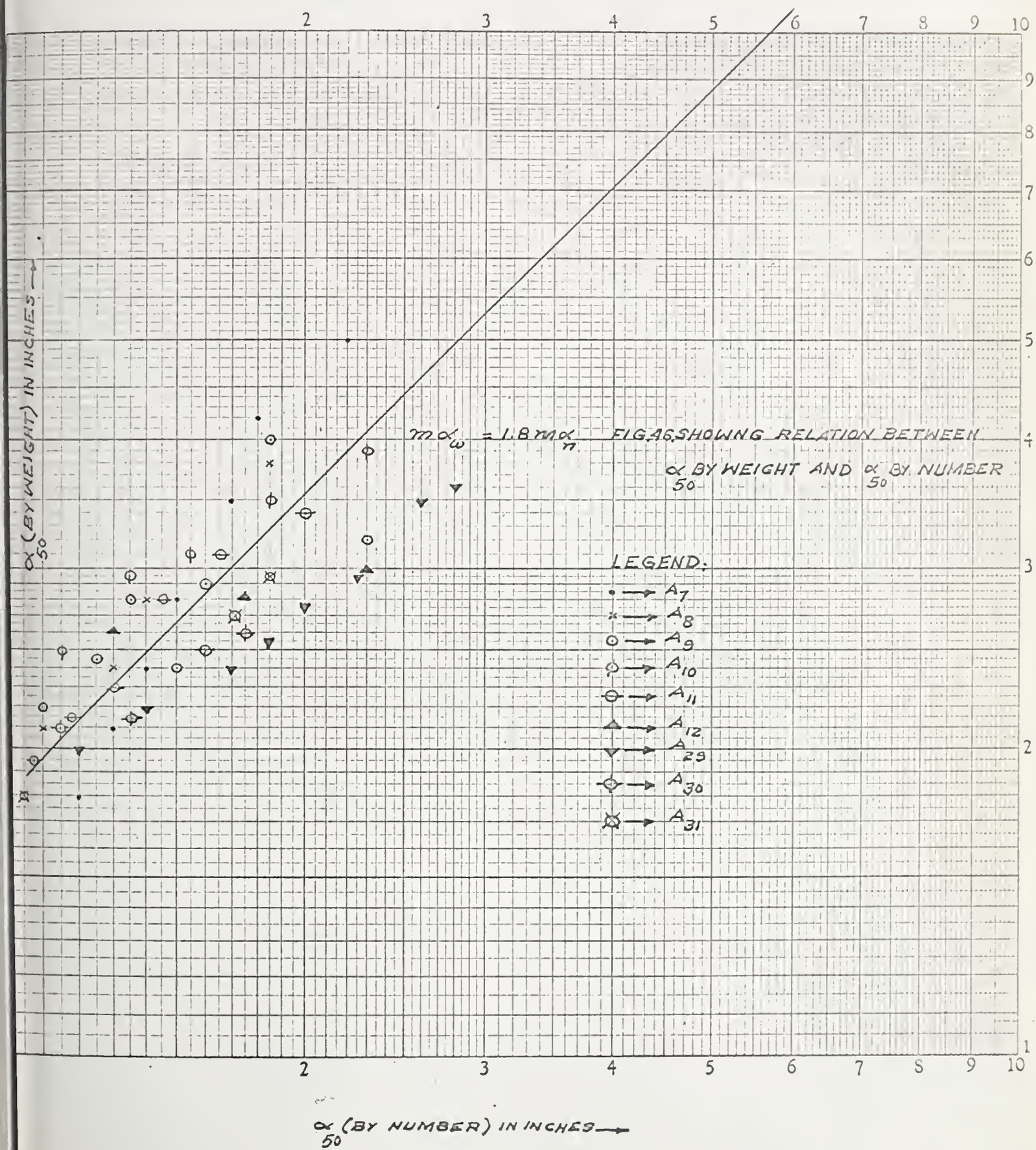


FIG. 46 SHOWING RELATION BETWEEN α_{50} BY WEIGHT AND α_{50} BY NUMBER

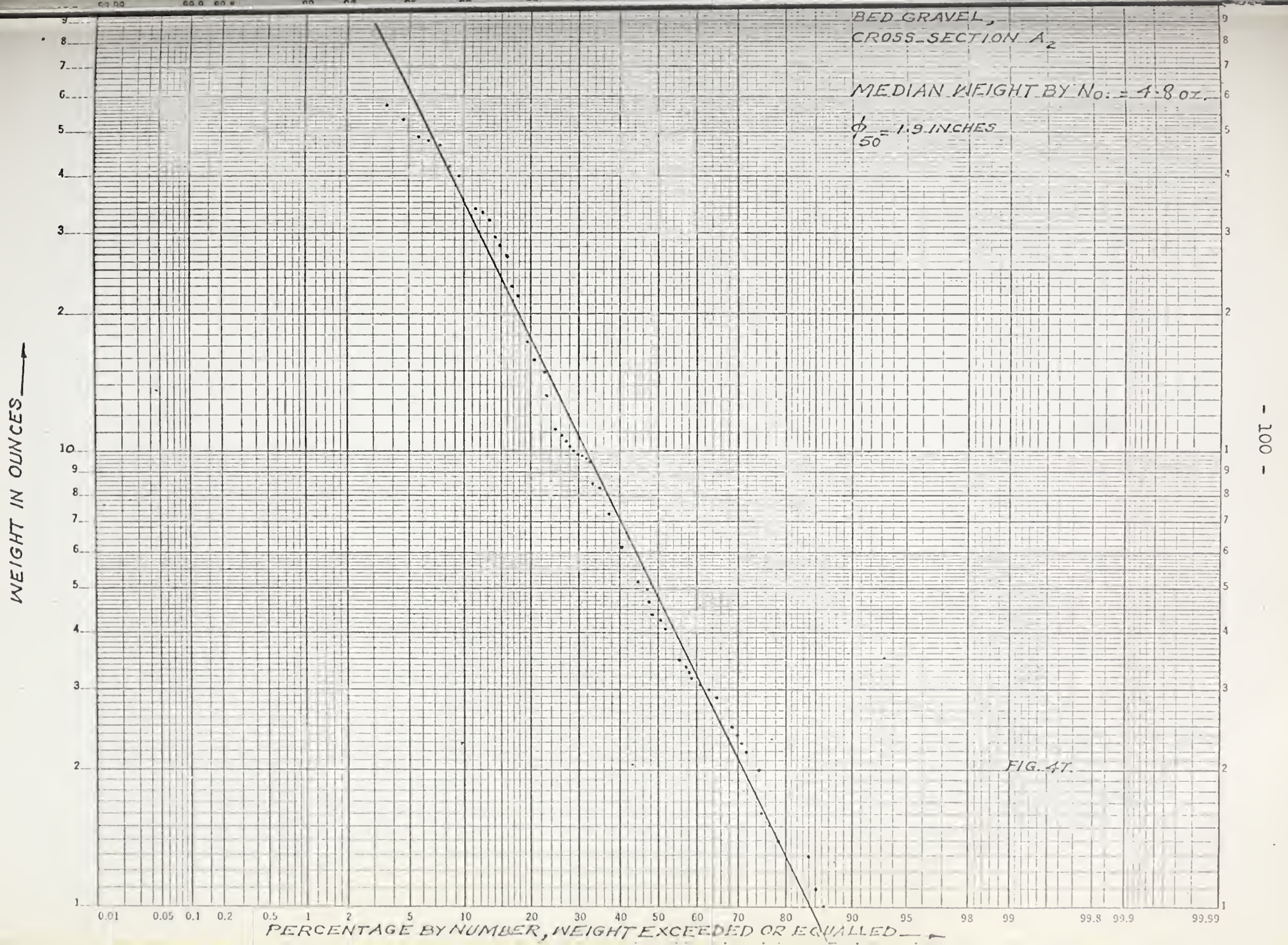

BED GRAVEL,
CROSS-SECTION A_2
MEDIAN WEIGHT BY No. = 4·8 oz.
ϕ_{50} = 1·9 INCHES
WEIGHT IN OUNCES
PERCENTAGE BY NUMBER, WEIGHT EXCEEDED OR EQUALLED
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99

FIG. 47.

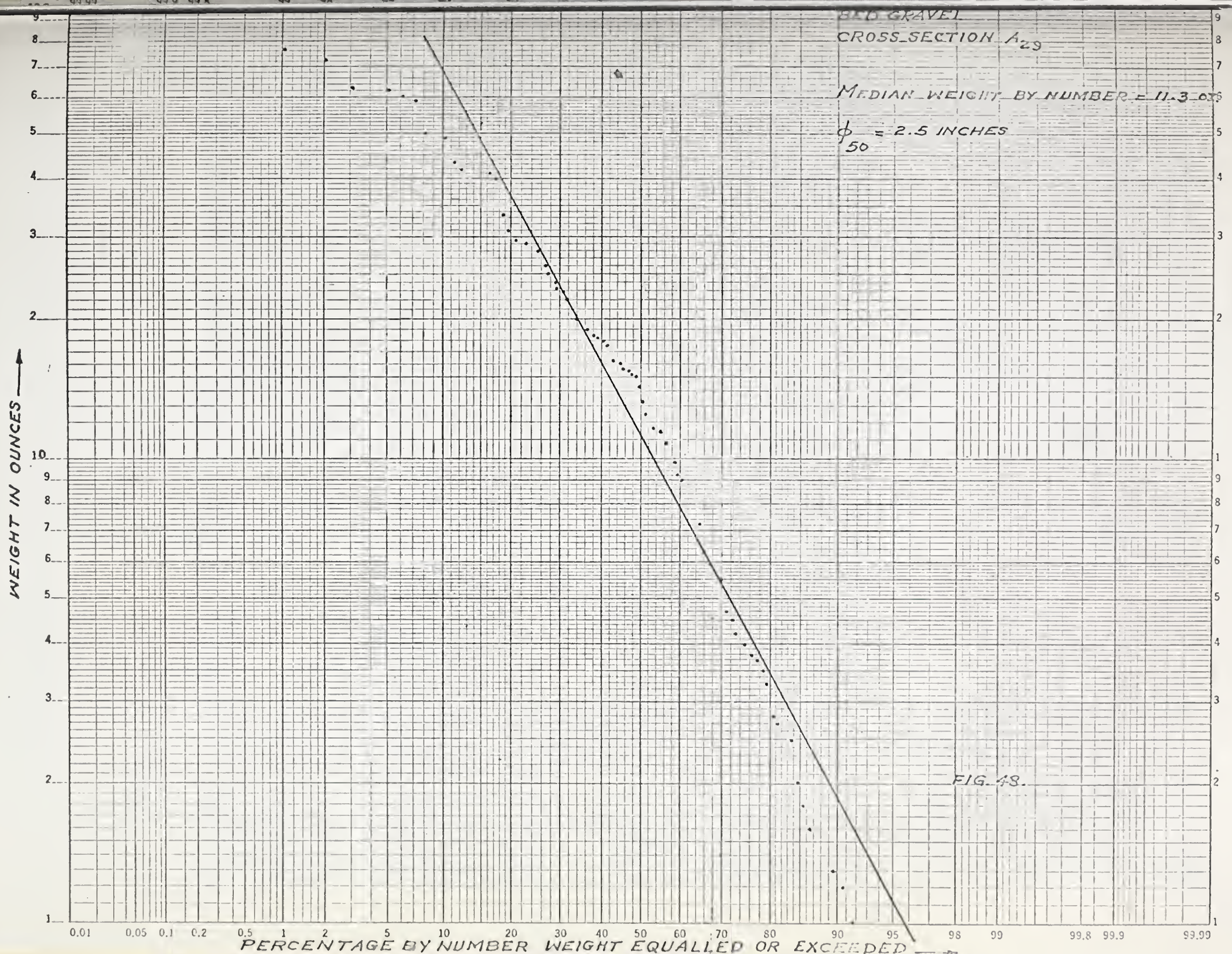

B.C.B. GRAVEL
CROSS-SECTION A29
MEDIAN WEIGHT BY NUMBER = 11.3 OZS.
ϕ_{50} = 2.5 INCHES
WEIGHT IN OUNCES
PERCENTAGE BY NUMBER WEIGHT EQUALLED OR EXCEEDED
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99

FIG. 48.

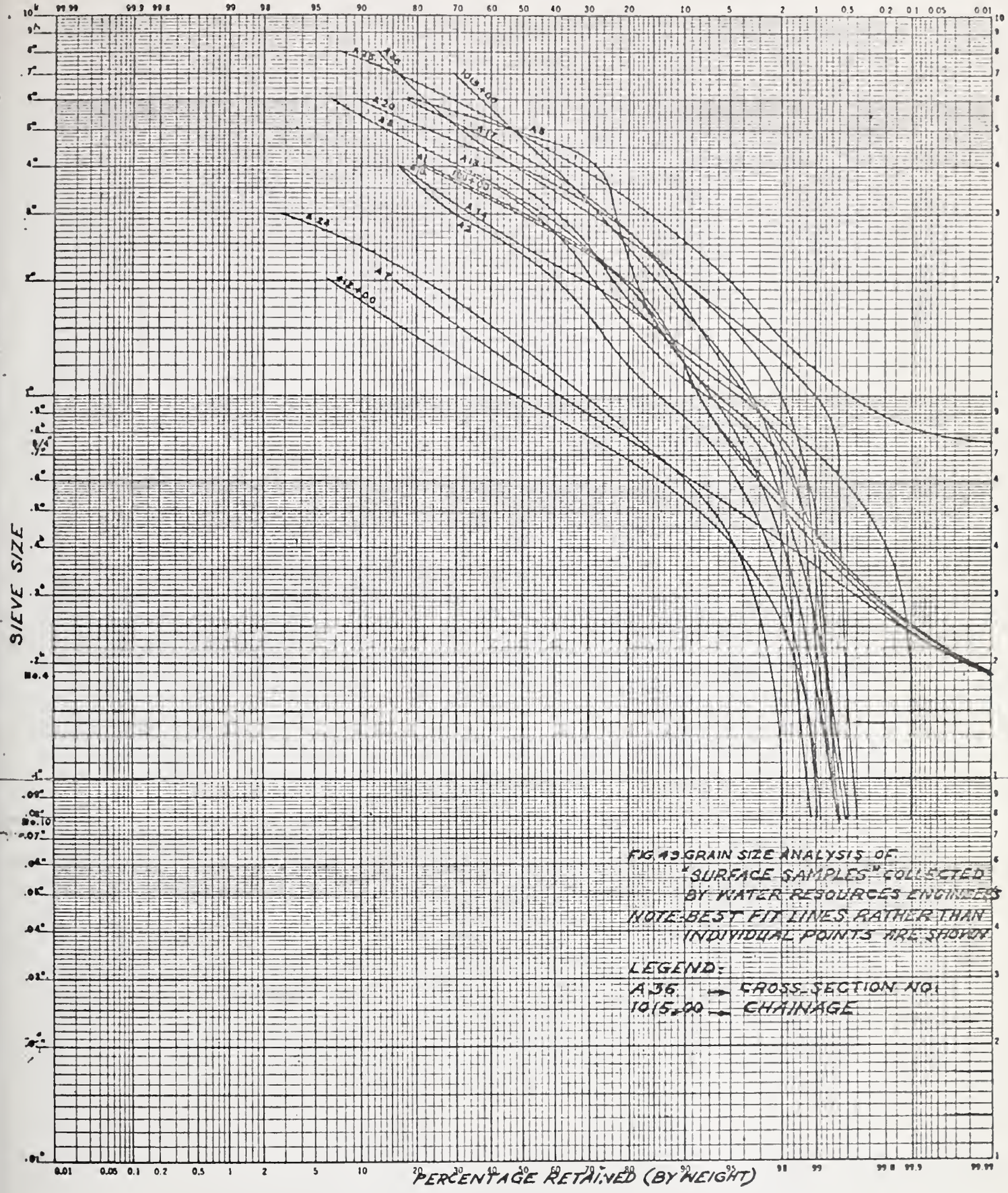


FIG 43 GRAIN SIZE ANALYSIS OF "SURFACE SAMPLES" COLLECTED BY WATER RESOURCES ENGINEERS

NOTE: BEST FIT LINES RATHER THAN INDIVIDUAL POINTS ARE SHOWN

LEGEND:

A 36 → CROSS SECTION NO.

1015.00 → CHAINAGE

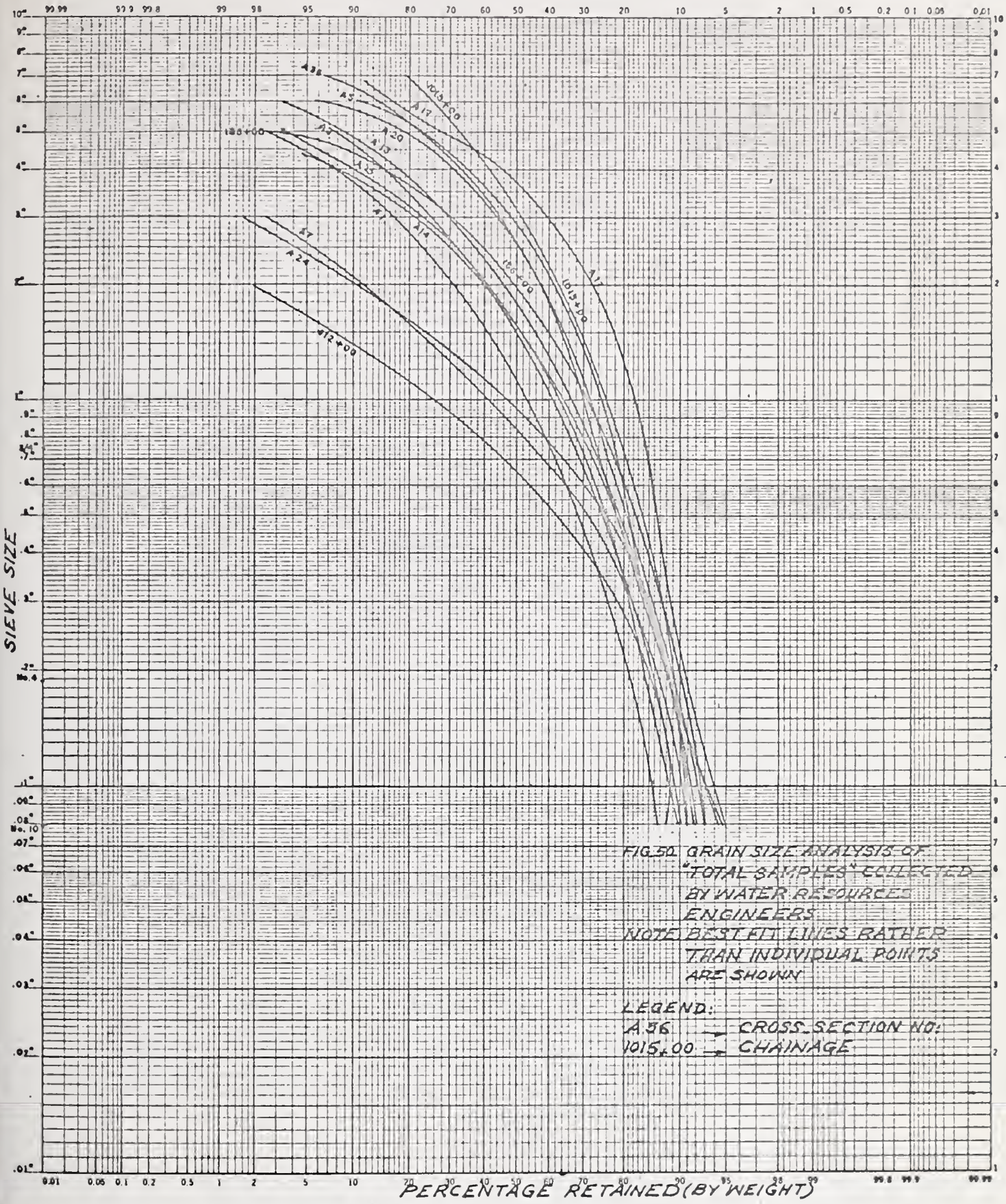


FIG 50. GRAIN SIZE ANALYSIS OF "TOTAL SAMPLES" COLLECTED BY WATER RESOURCES ENGINEERS

NOTE: BEST FIT LINES RATHER THAN INDIVIDUAL POINTS ARE SHOWN

LEGEND:
A 36 → CROSS SECTION NO:
1015+00 → CHAINAGE

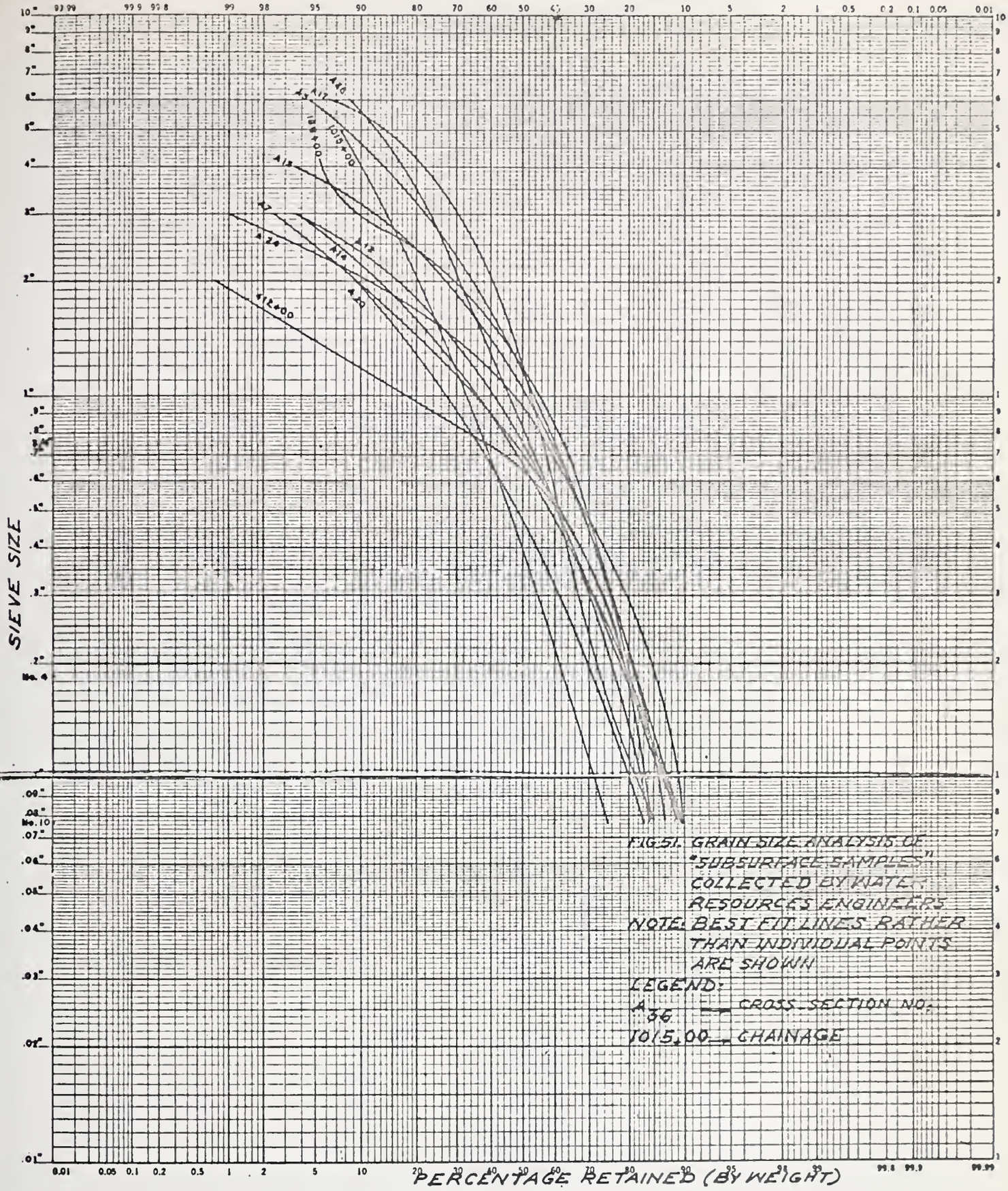


FIG 51. GRAIN SIZE ANALYSIS OF "SUBSURFACE SAMPLES" COLLECTED BY WATER RESOURCES ENGINEERS

NOTE: BEST FIT LINES RATHER THAN INDIVIDUAL POINTS ARE SHOWN

LEGEND:

A 36 — CROSS SECTION NO.

1015.00 — CHAINAGE

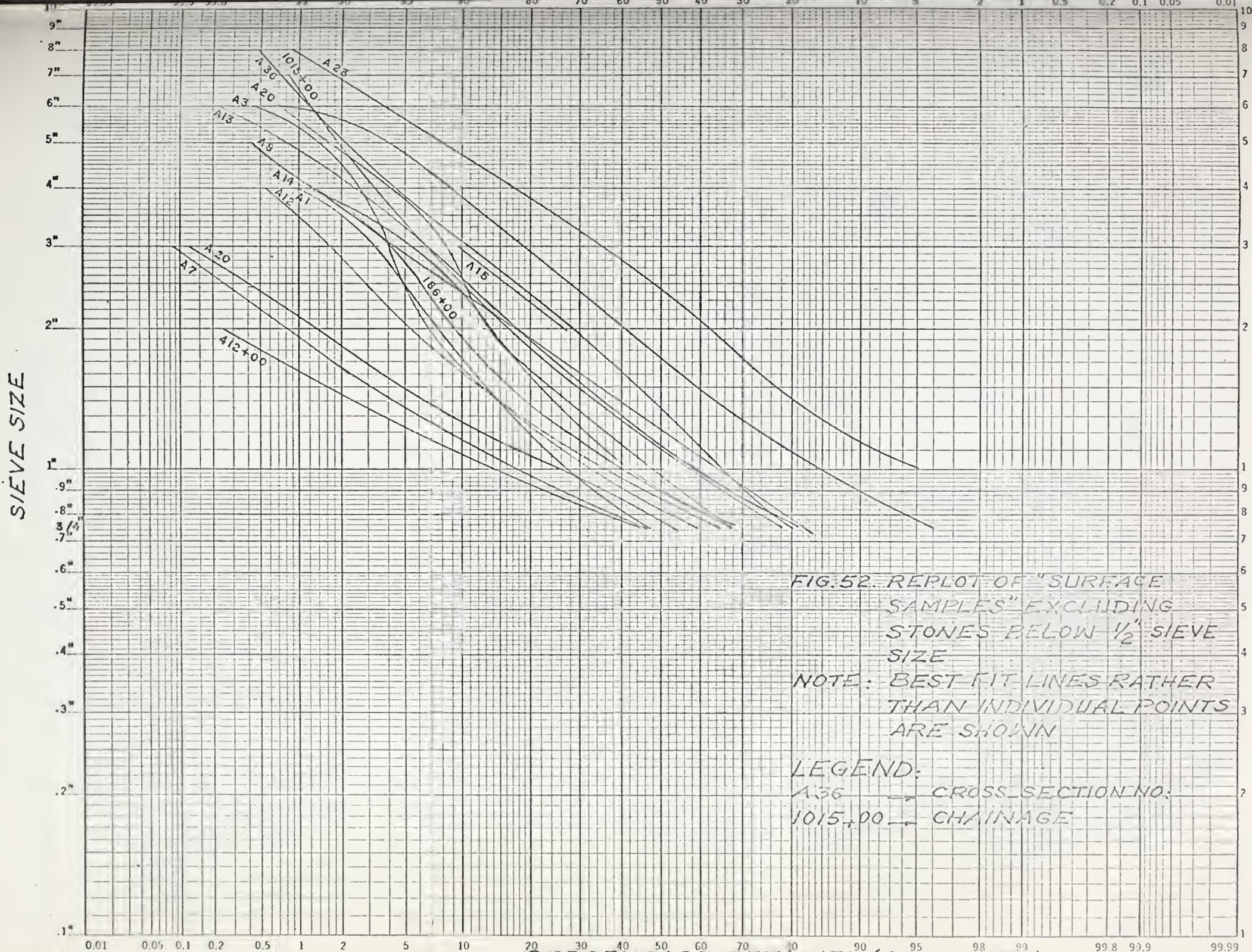


FIG:52. REPLOT OF "SURFACE SAMPLES" EXCLUDING STONES BELOW 1/2" SIEVE SIZE

NOTE: BEST FIT LINES RATHER THAN INDIVIDUAL POINTS ARE SHOWN

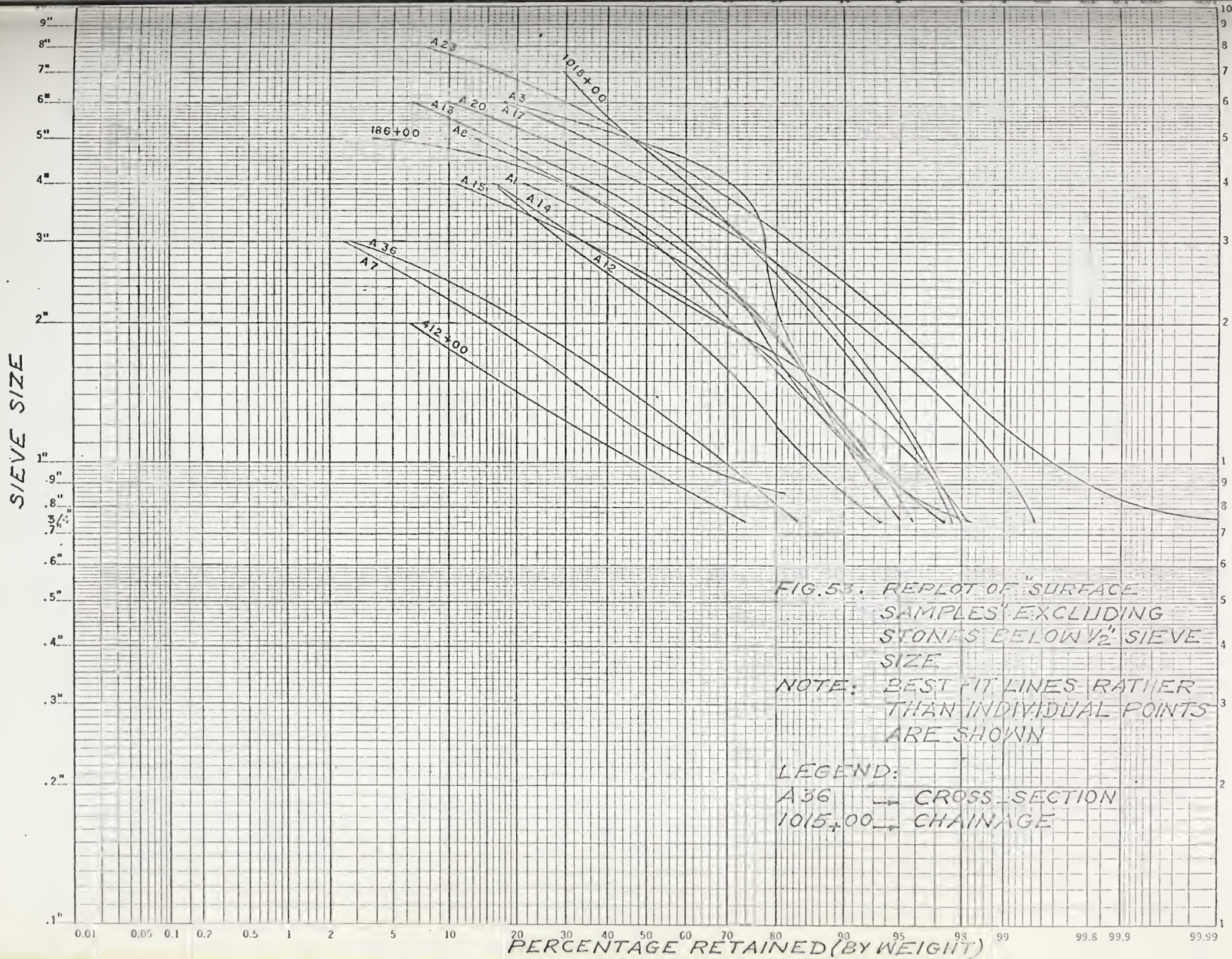


FIG. 53. REPLOT OF "SURFACE SAMPLES" EXCLUDING STONES BELOW ½" SIEVE SIZE

NOTE: BEST FIT LINES RATHER THAN INDIVIDUAL POINTS ARE SHOWN

LEGEND:
A36 — CROSS-SECTION
1015+00 — CHAINAGE

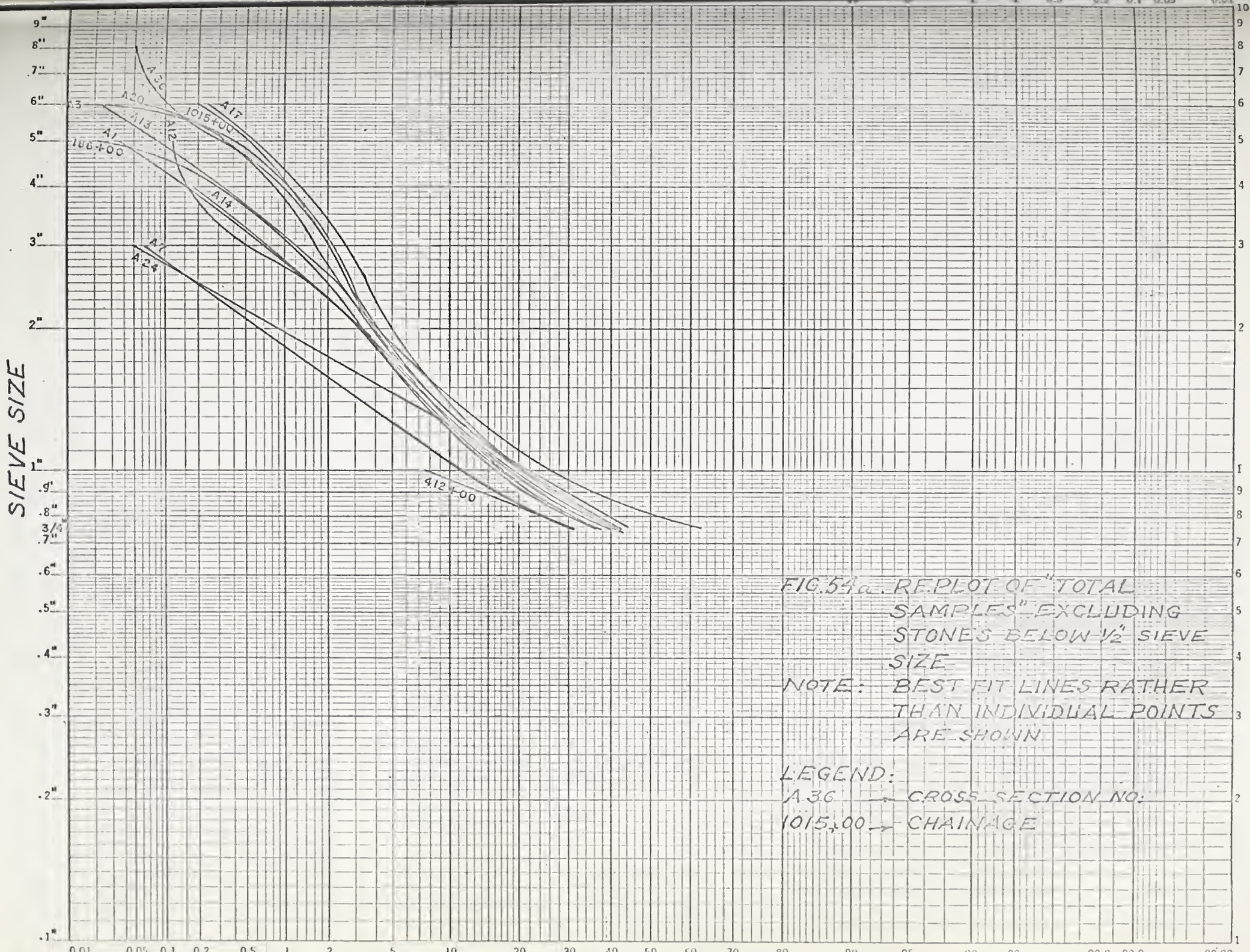


FIG. 54a. REPLOT OF "TOTAL SAMPLES" EXCLUDING STONES BELOW ½" SIEVE SIZE

NOTE: BEST FIT LINES RATHER THAN INDIVIDUAL POINTS ARE SHOWN

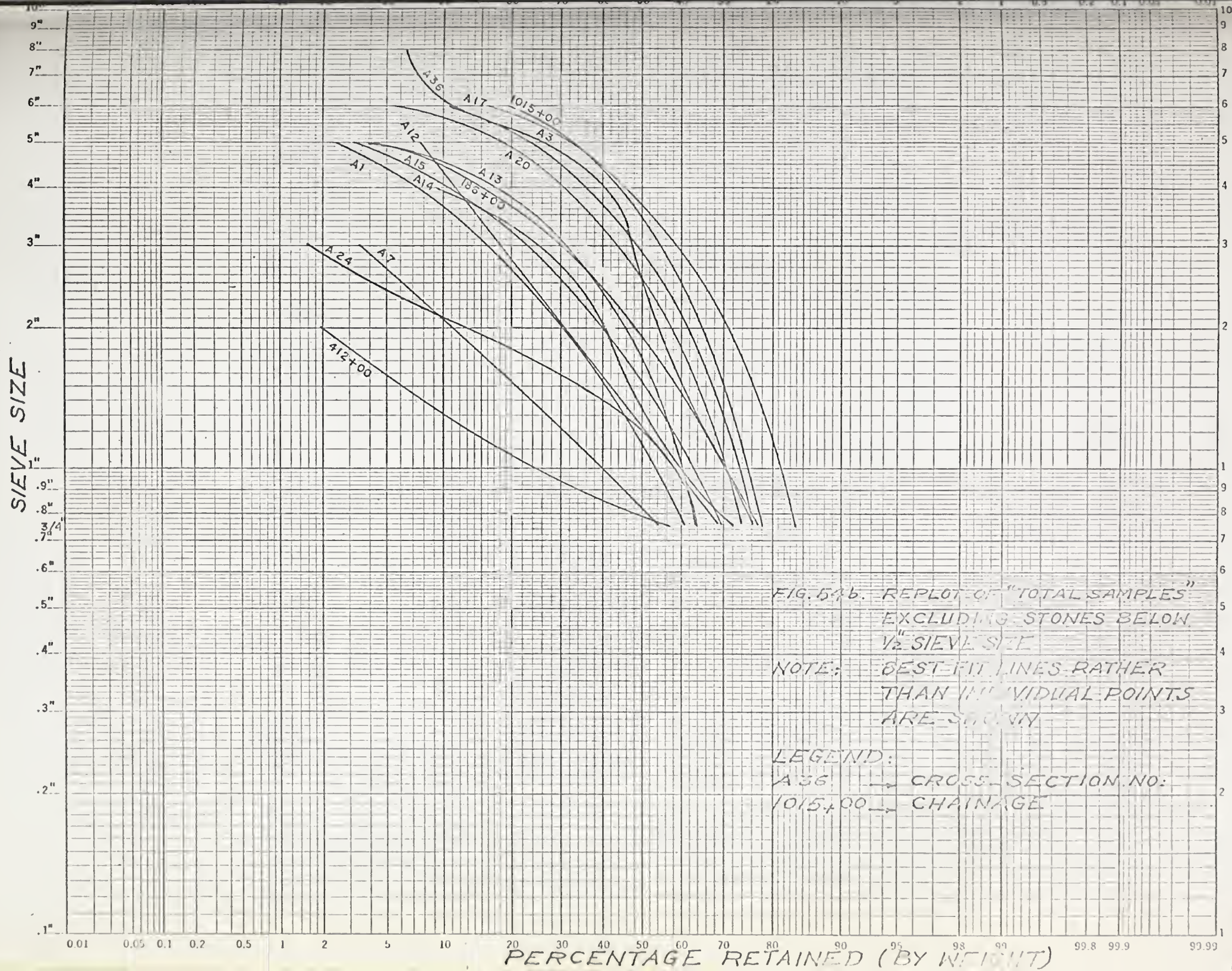


FIG. 54b. REPLOT OF "TOTAL SAMPLES" EXCLUDING STONES BELOW ½" SIEVE SIZE

NOTE: BEST FIT LINES RATHER THAN INDIVIDUAL POINTS ARE SHOWN

LEGEND:
A36 → CROSS-SECTION NO:
1015+00 → CHAINAGE

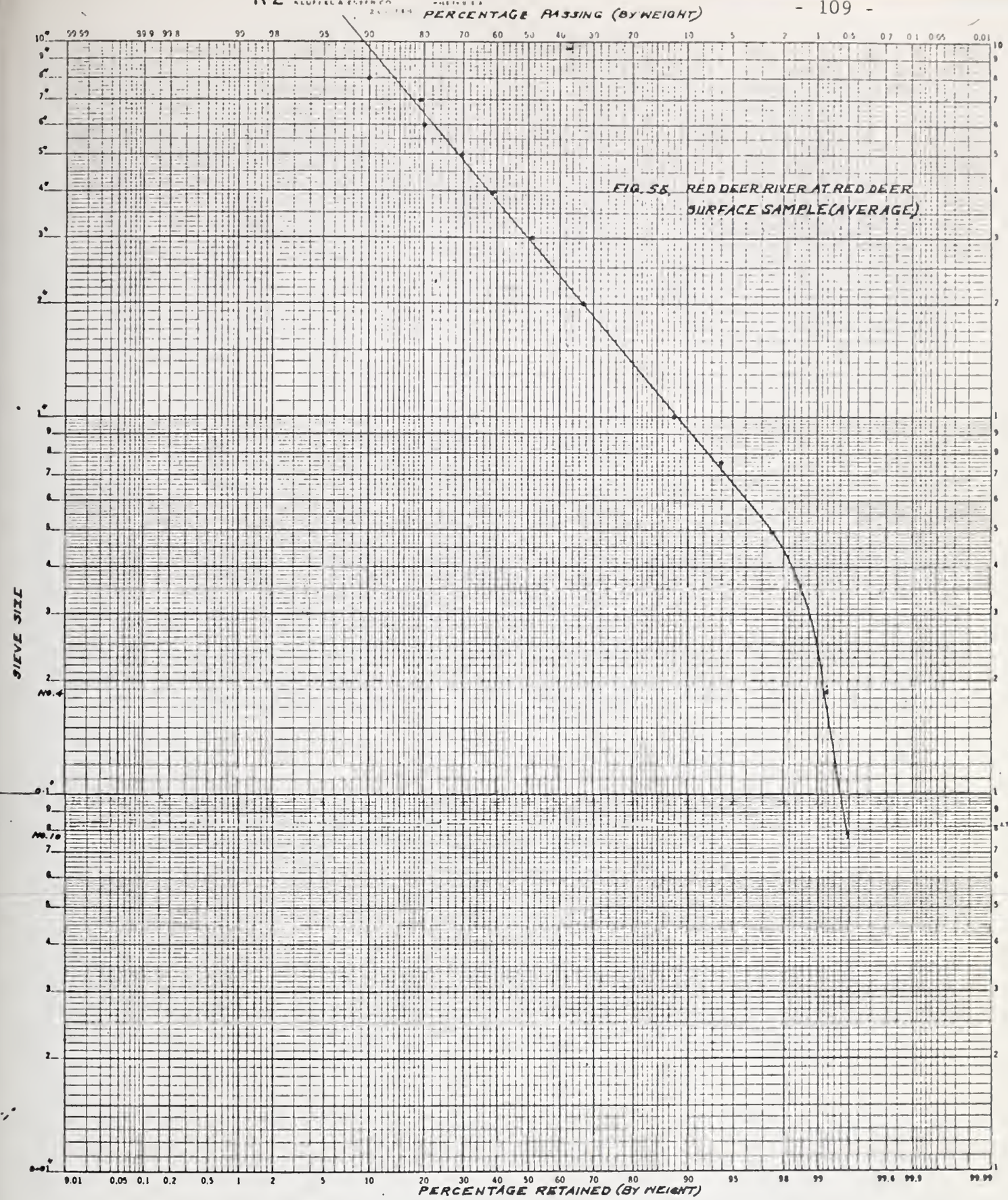


FIG. 58. RED DEER RIVER AT RED DEER.
SURFACE SAMPLE (AVERAGE)

- 109 -

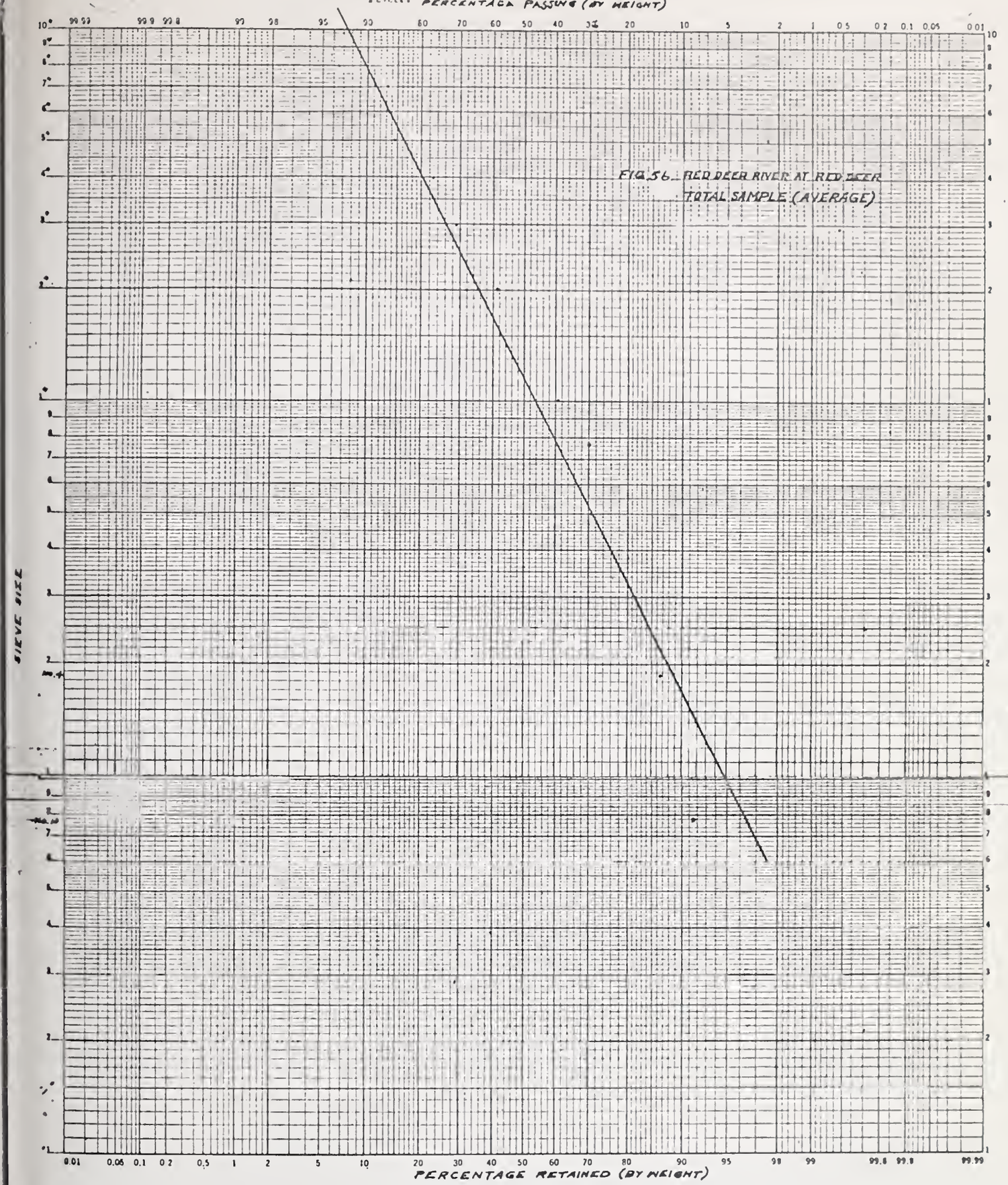


FIG. 56 RED DEER RIVER AT RED DEER
TOTAL SAMPLE (AVERAGE)

- 110 -

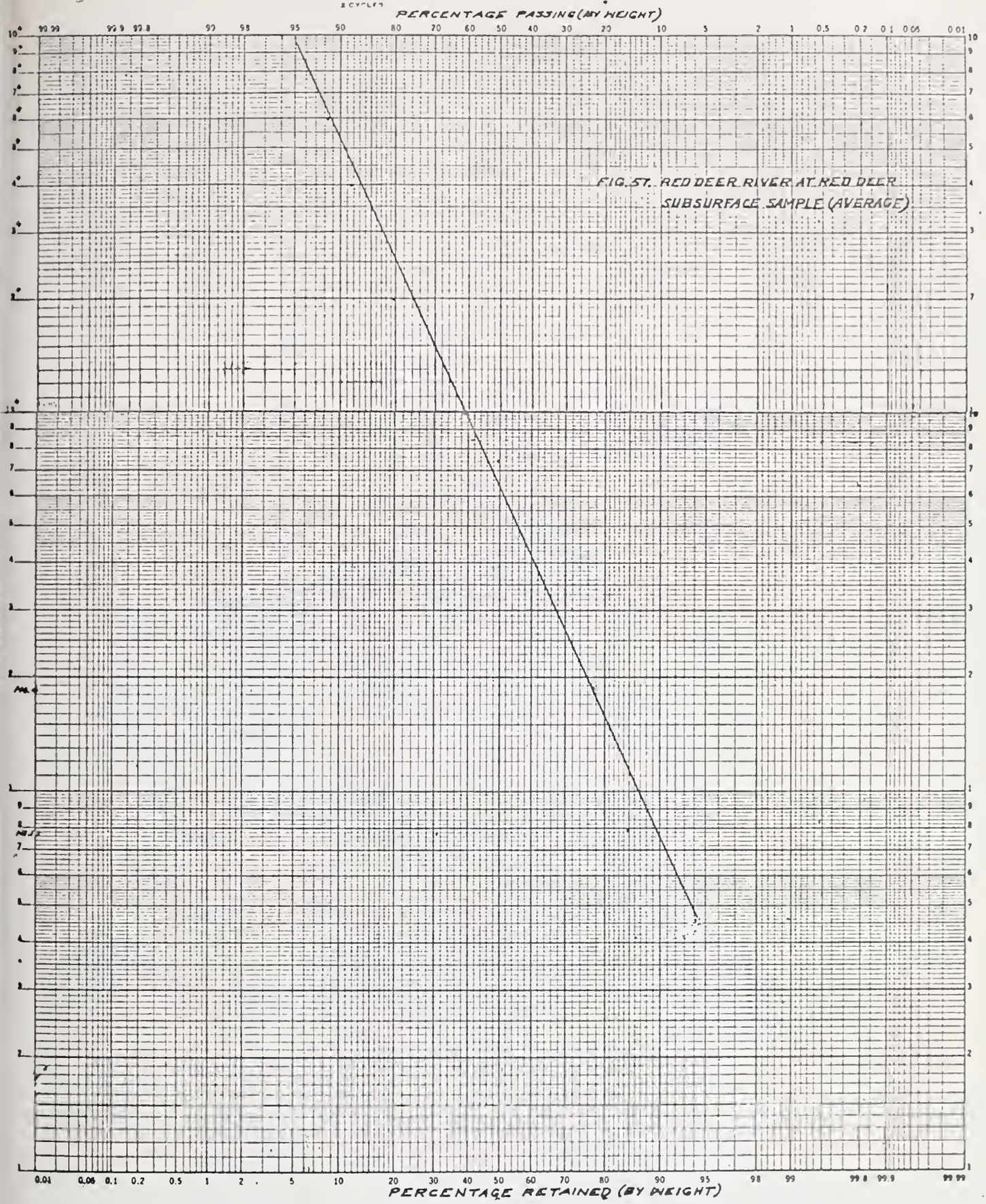


FIG. 57. RED DEER RIVER AT RED DEER
SUBSURFACE SAMPLE (AVERAGE)

- 111 -

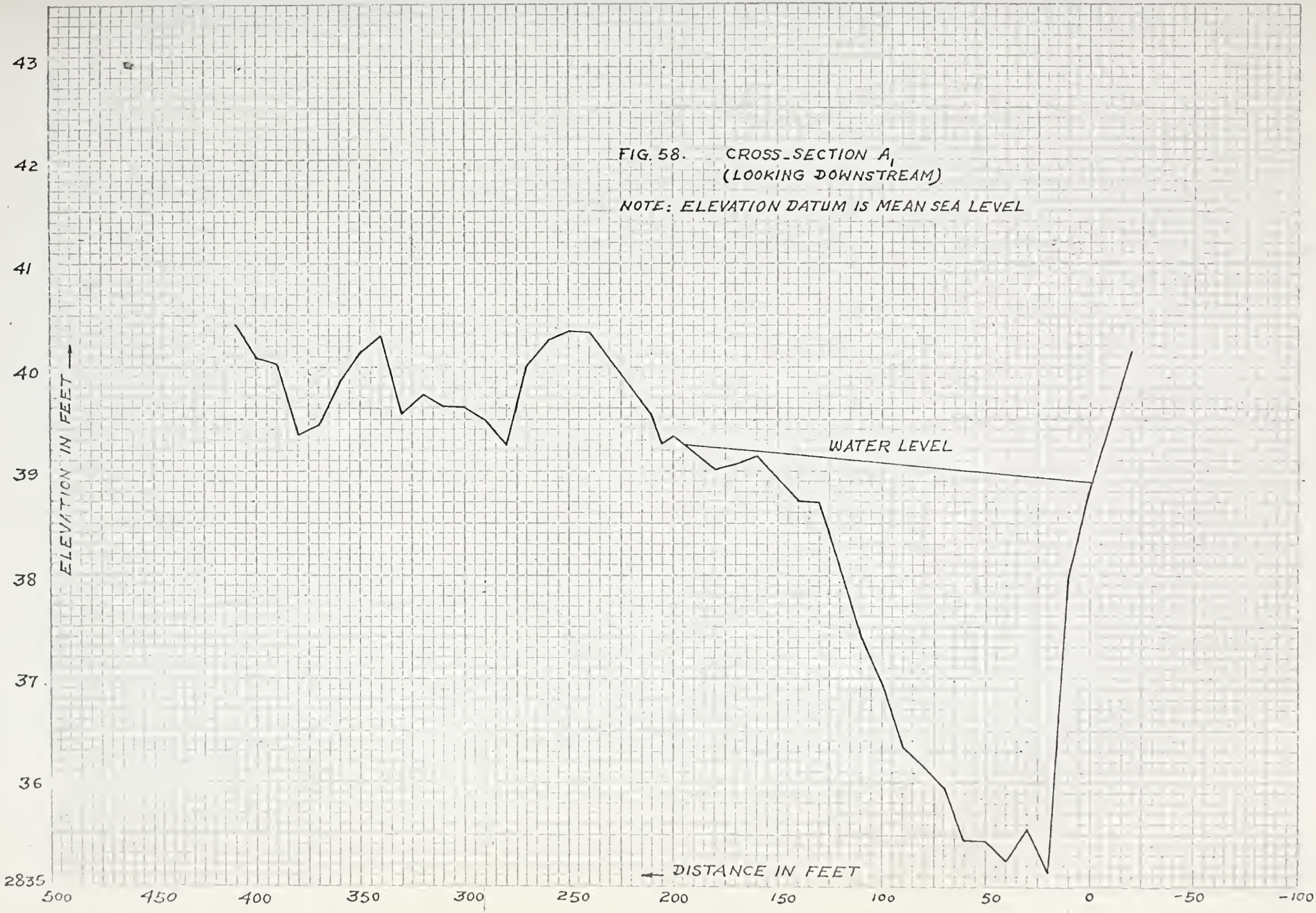


FIG. 58. CROSS-SECTION A,
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

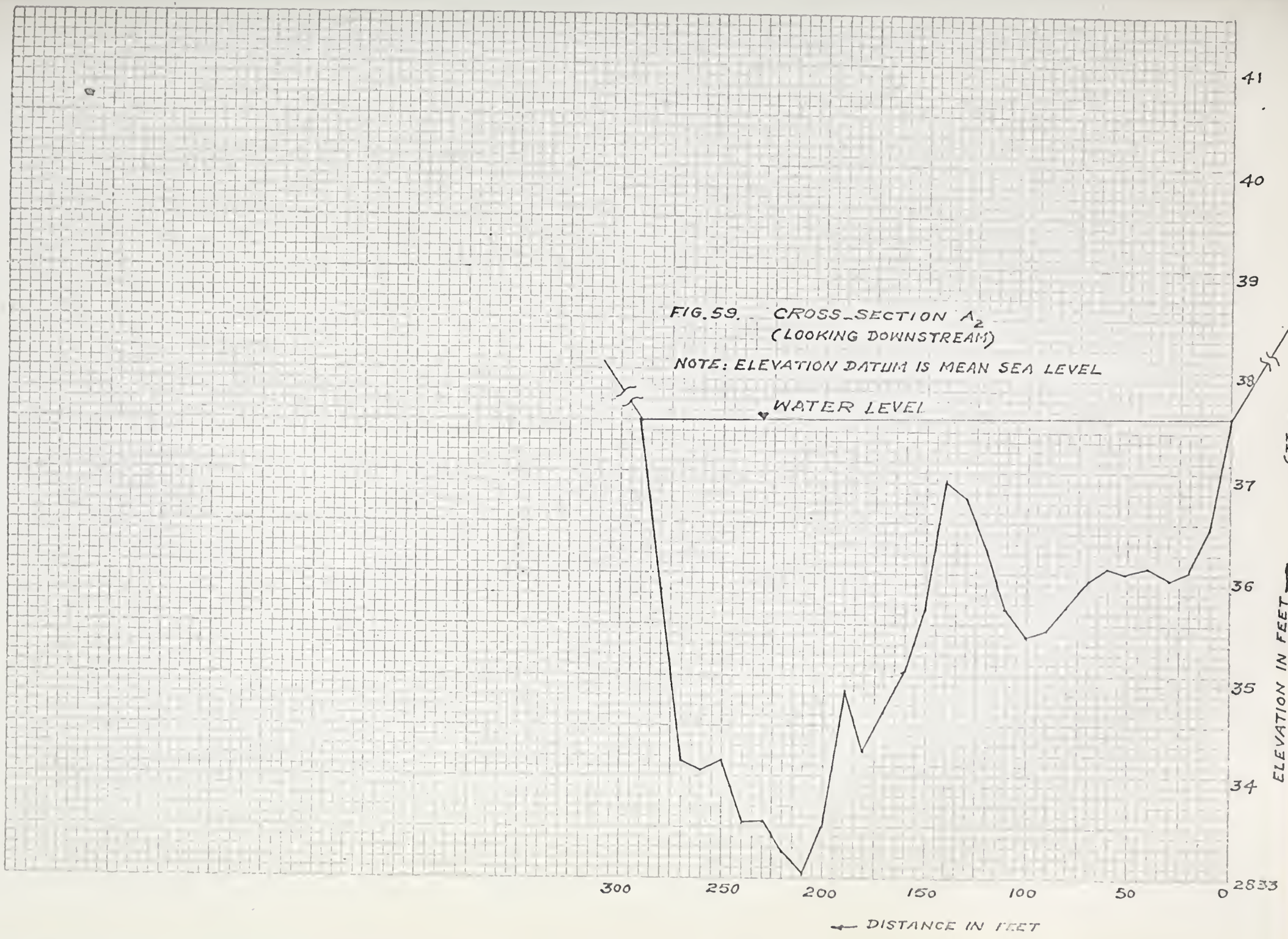


FIG. 59. CROSS-SECTION A_2 (LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL



FIG. 60. CROSS-SECTION A_3
(LOOKING DOWNSTREAM)
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

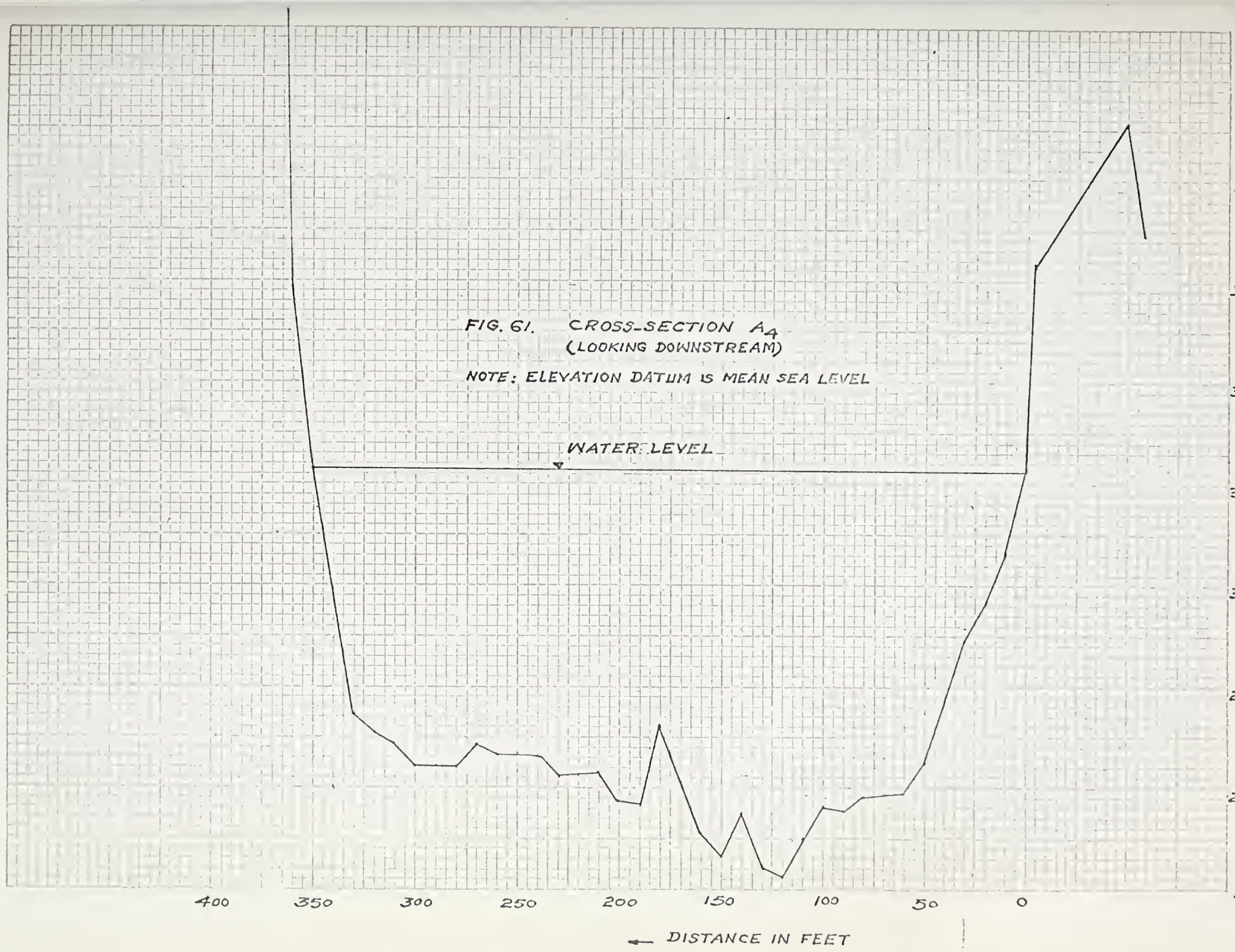
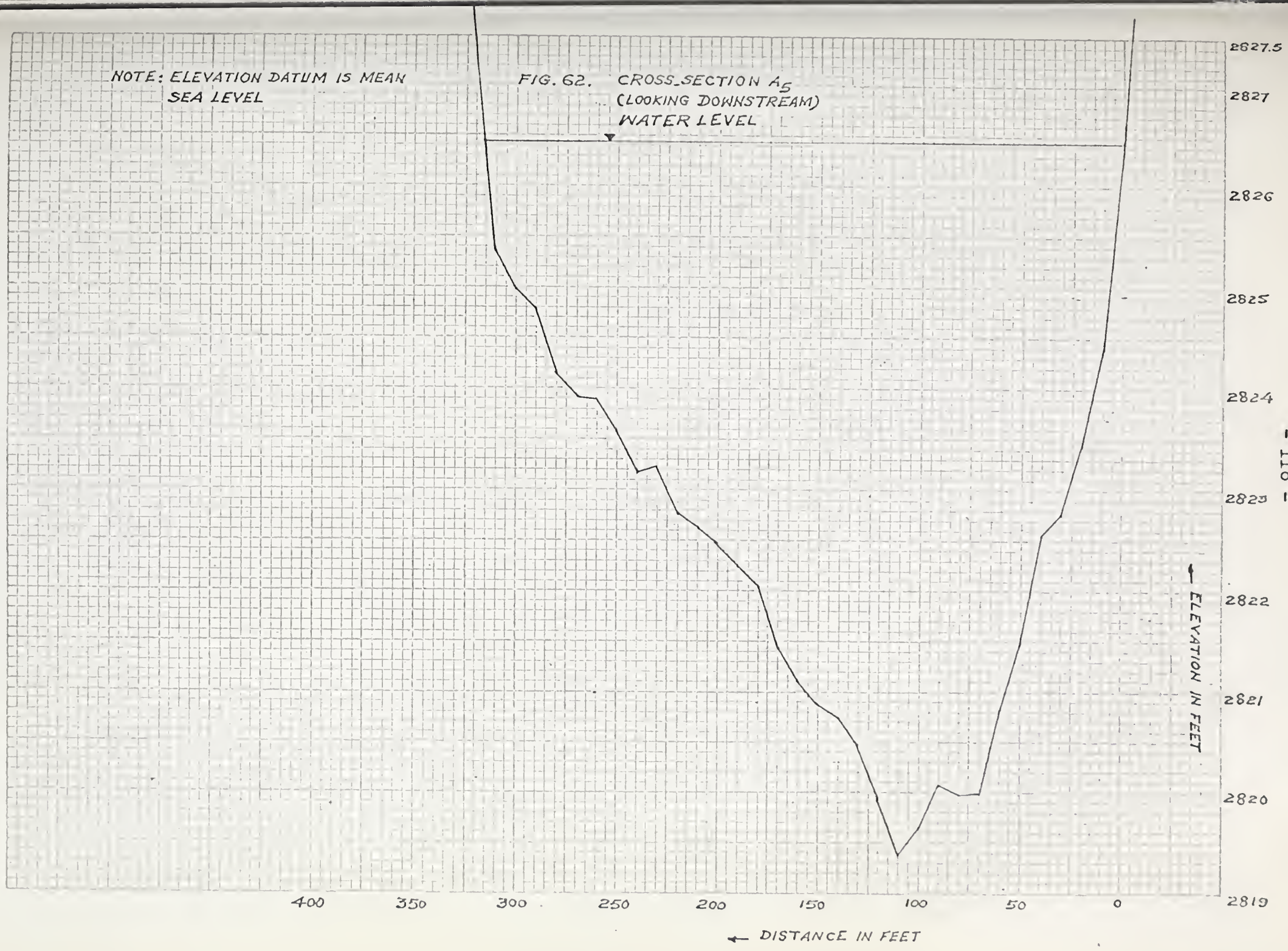


FIG. 61. CROSS-SECTION A_4
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL


NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
FIG. 62. CROSS-SECTION A_5 (LOOKING DOWNSTREAM) WATER LEVEL
2827.5
2827
2826
2825
2824
2823
2822
2821
2820
2819
← ELEVATION IN FEET
400
350
300
250
200
150
100
50
0
← DISTANCE IN FEET

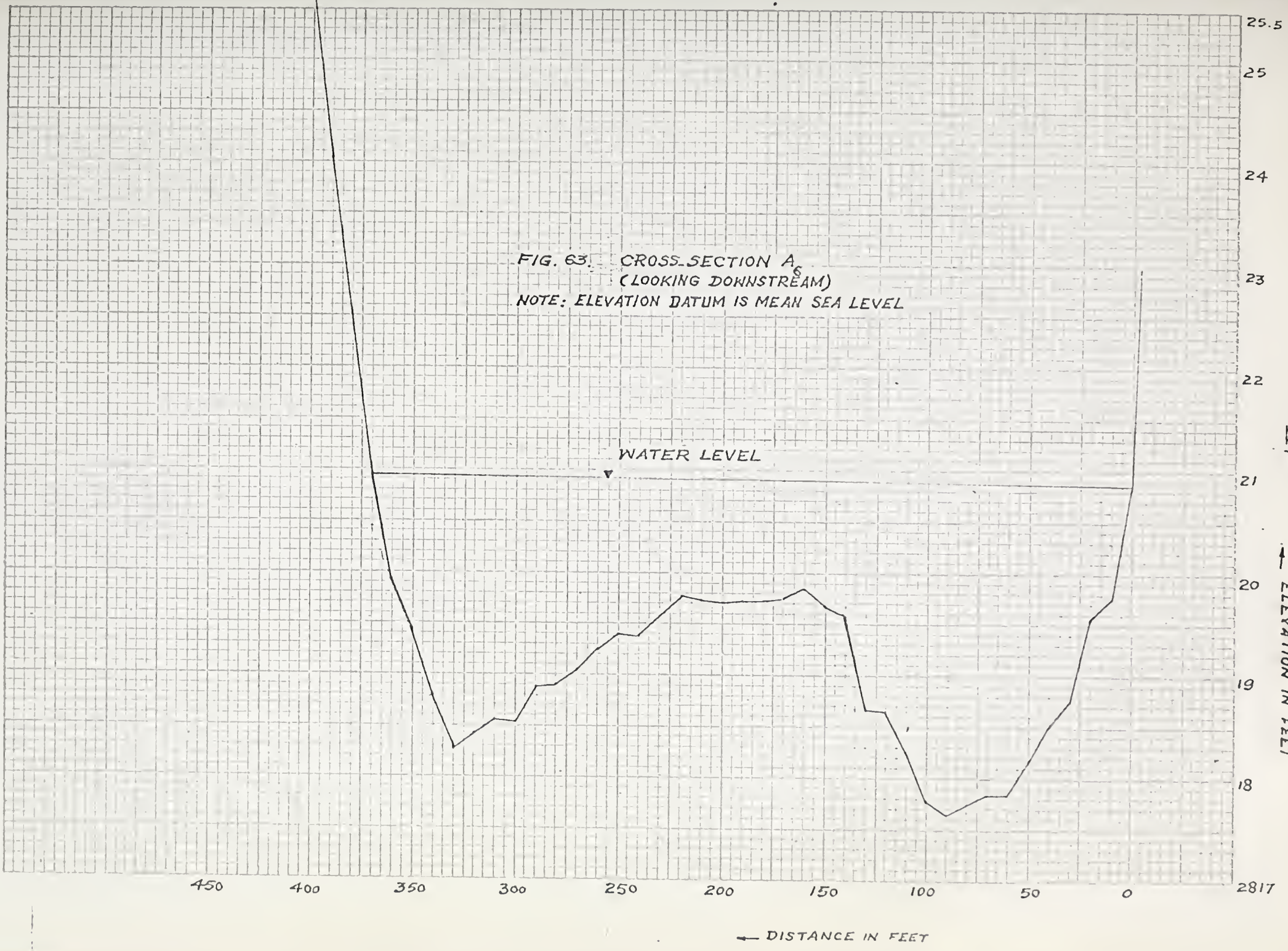


FIG. 63. CROSS-SECTION A6
(LOOKING DOWNSTREAM)
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

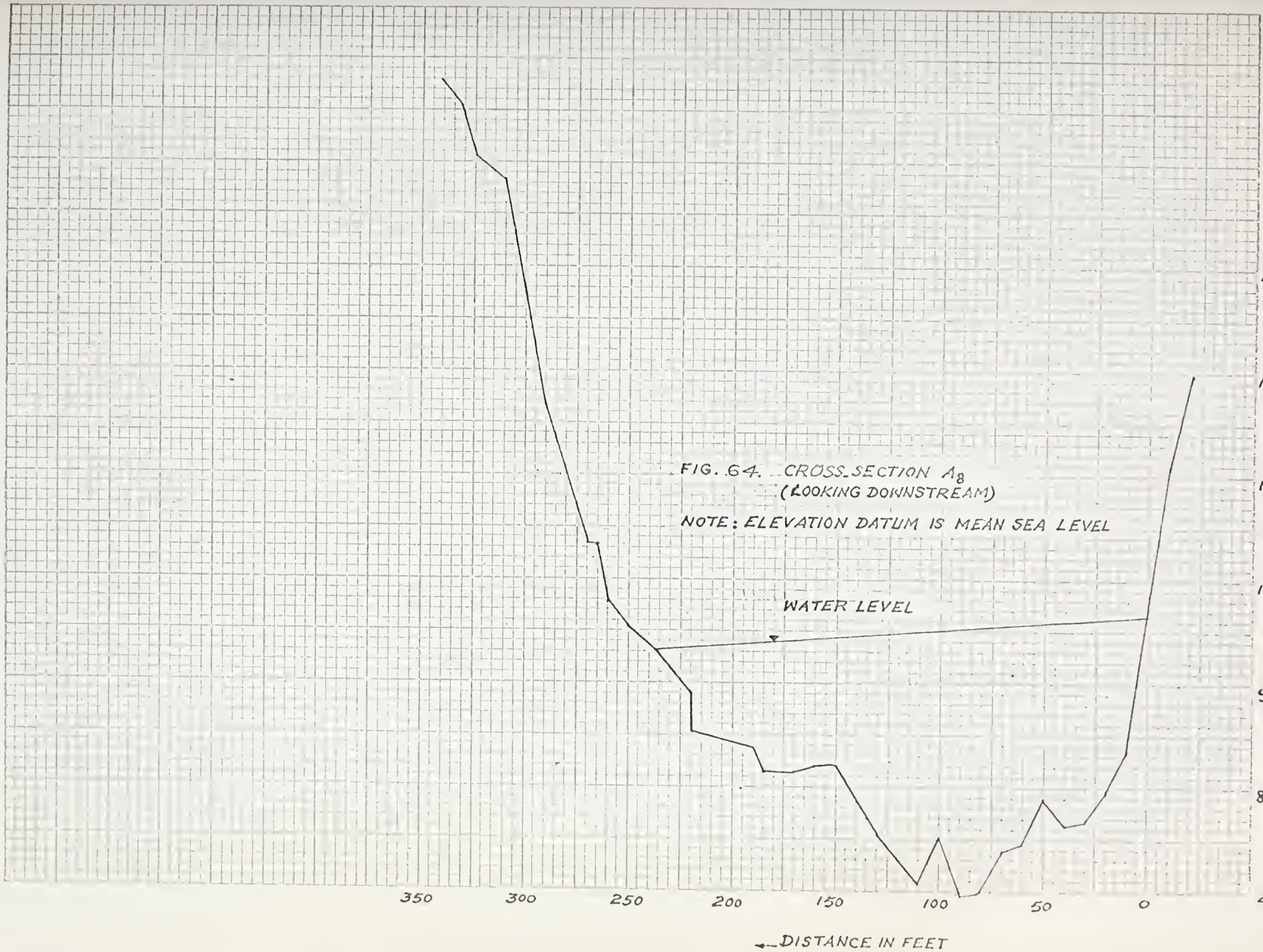


FIG. 64. CROSS-SECTION A_8
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

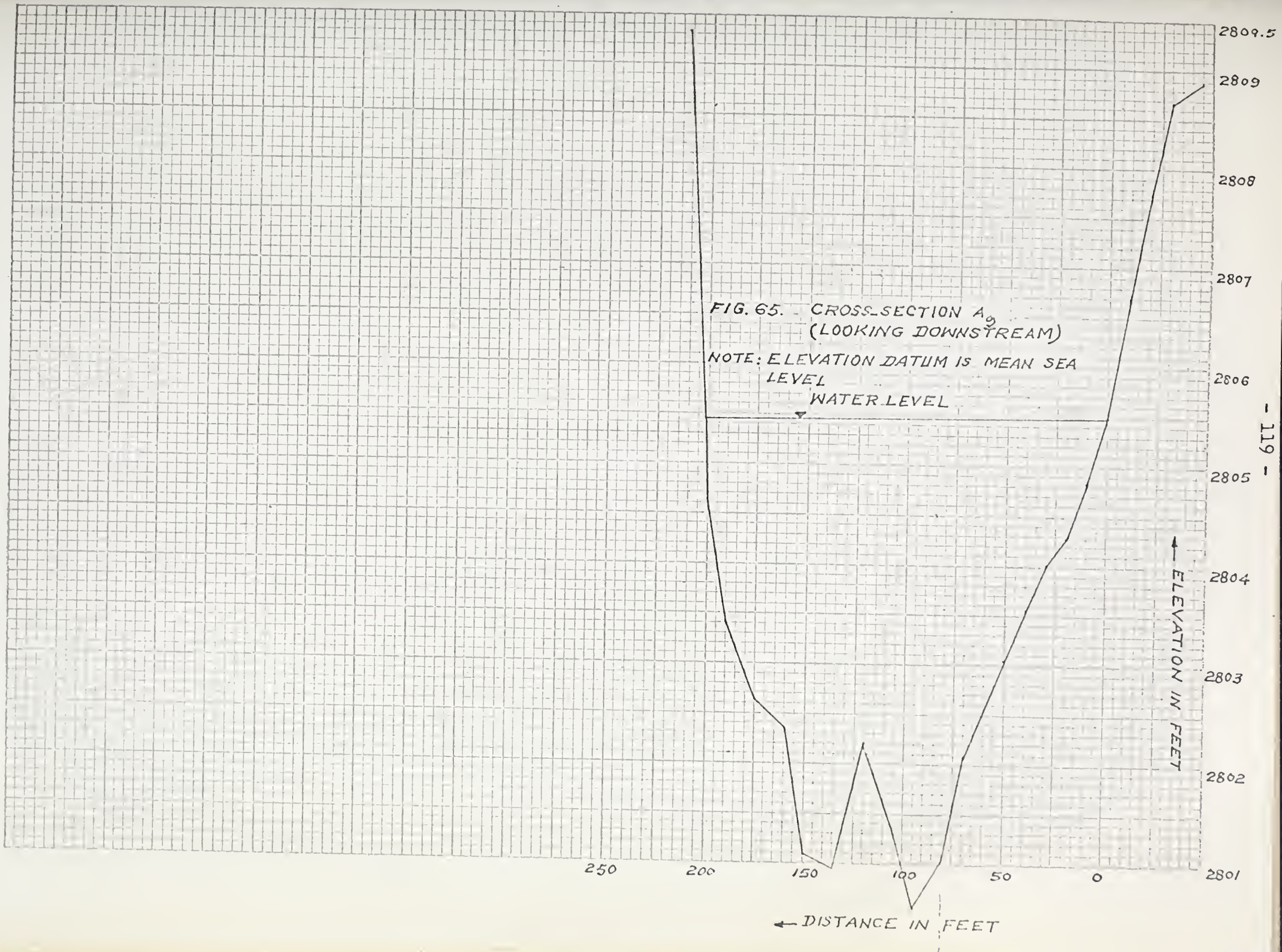


FIG. 65. CROSS-SECTION A_9
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

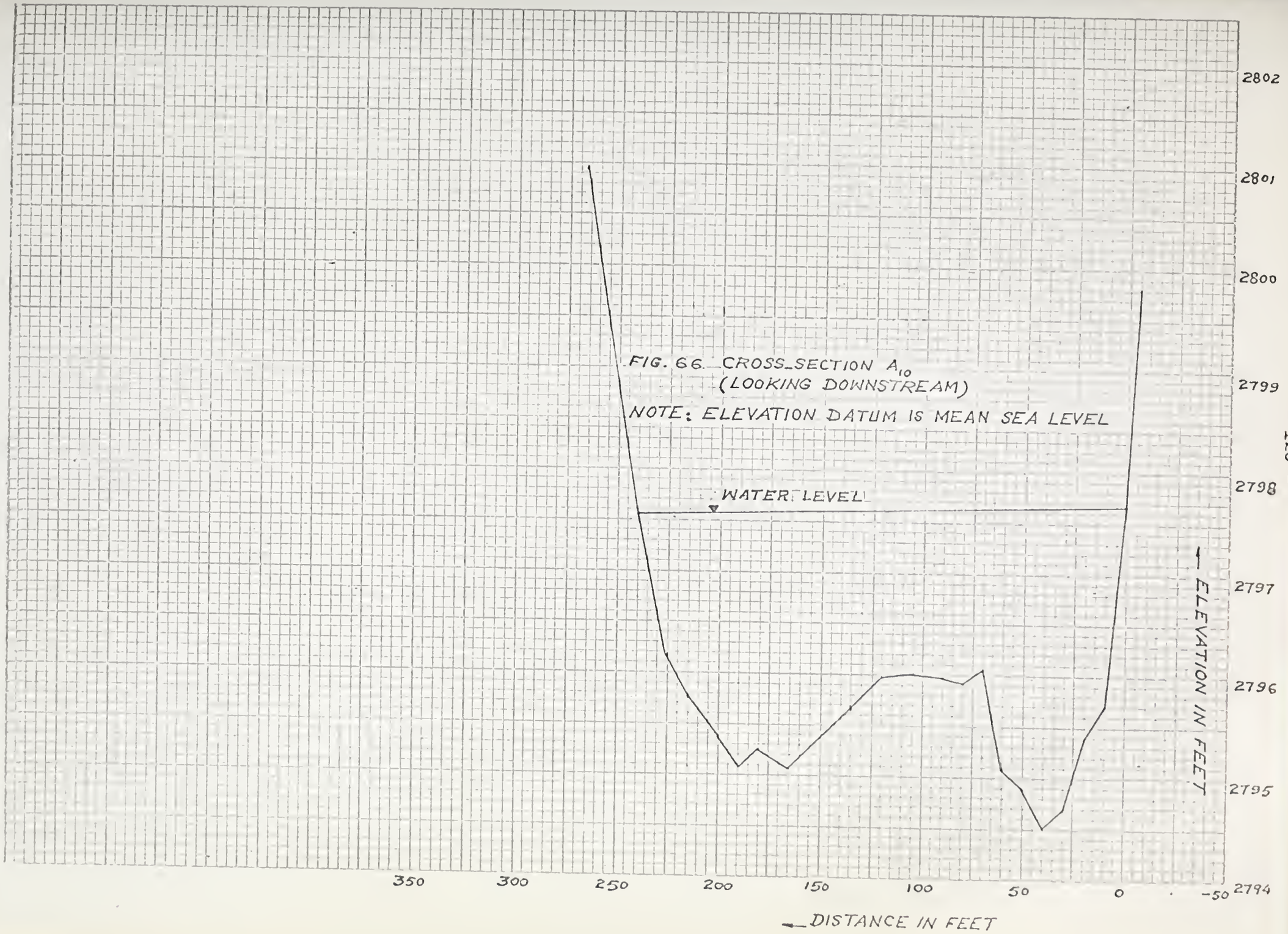


FIG. 66. CROSS-SECTION A_{10}
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

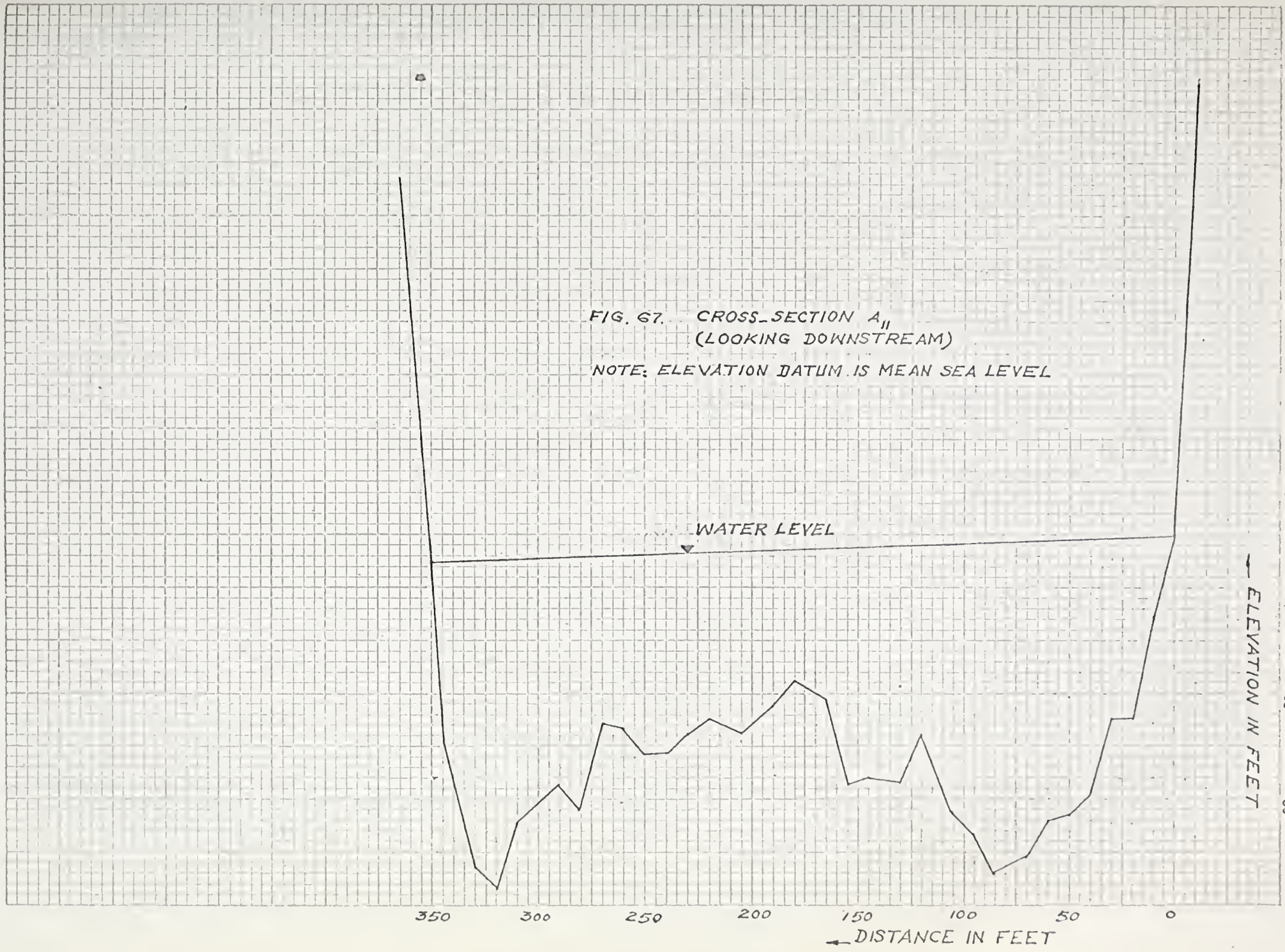


FIG. 67. CROSS-SECTION A_{II}
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

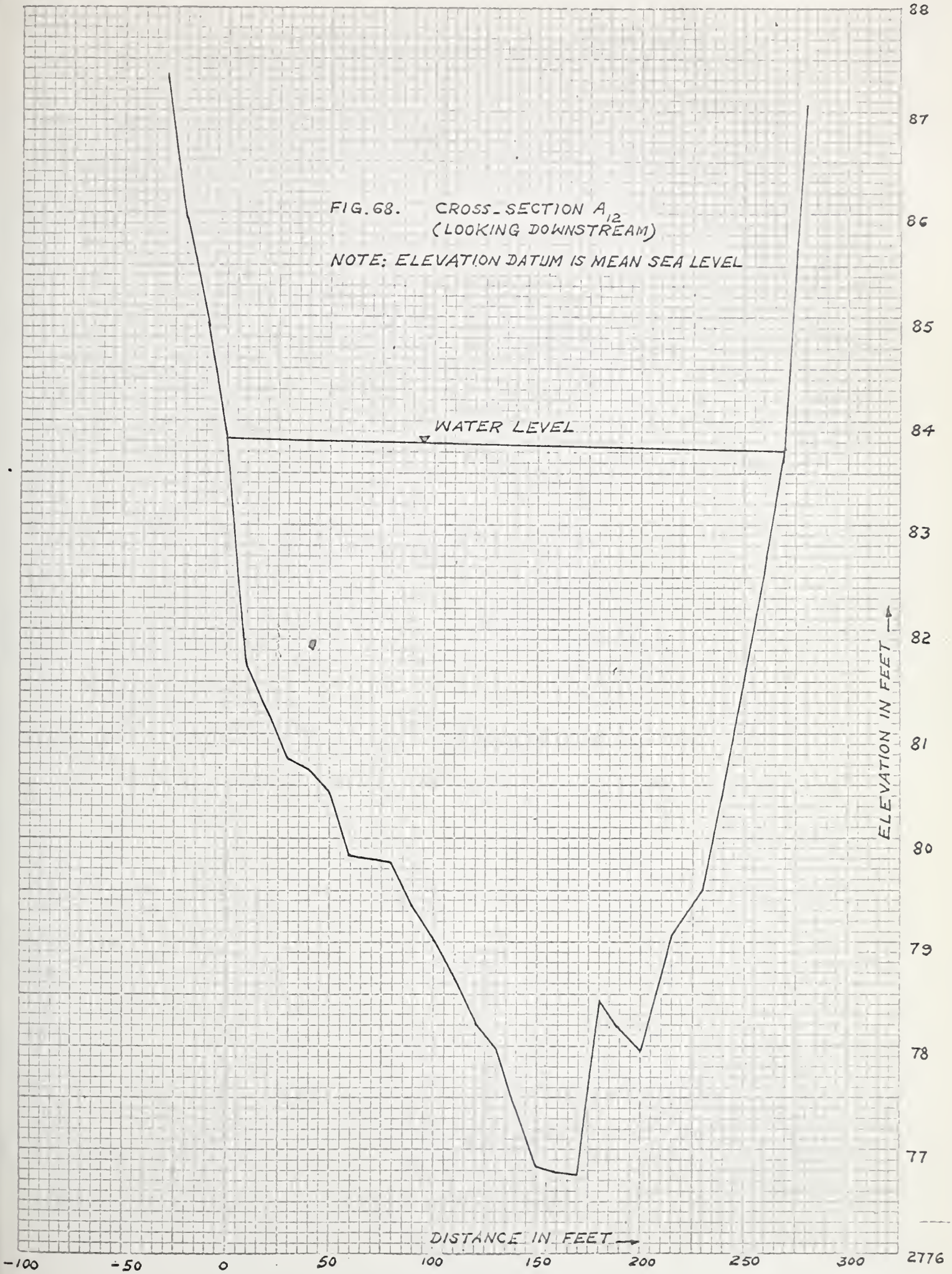


FIG. 68. CROSS-SECTION A_{12} (LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

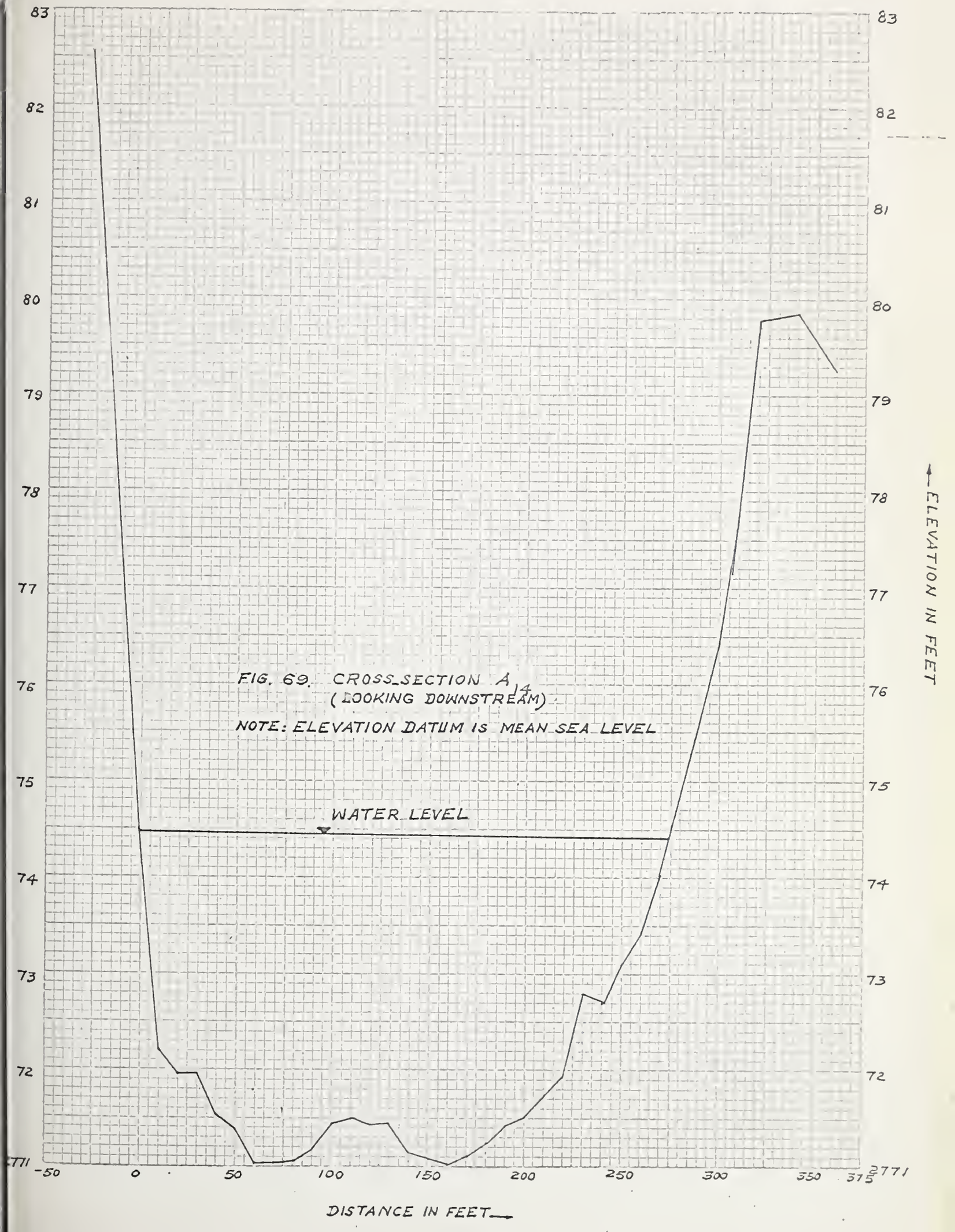


FIG. 69. CROSS-SECTION A-A'
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

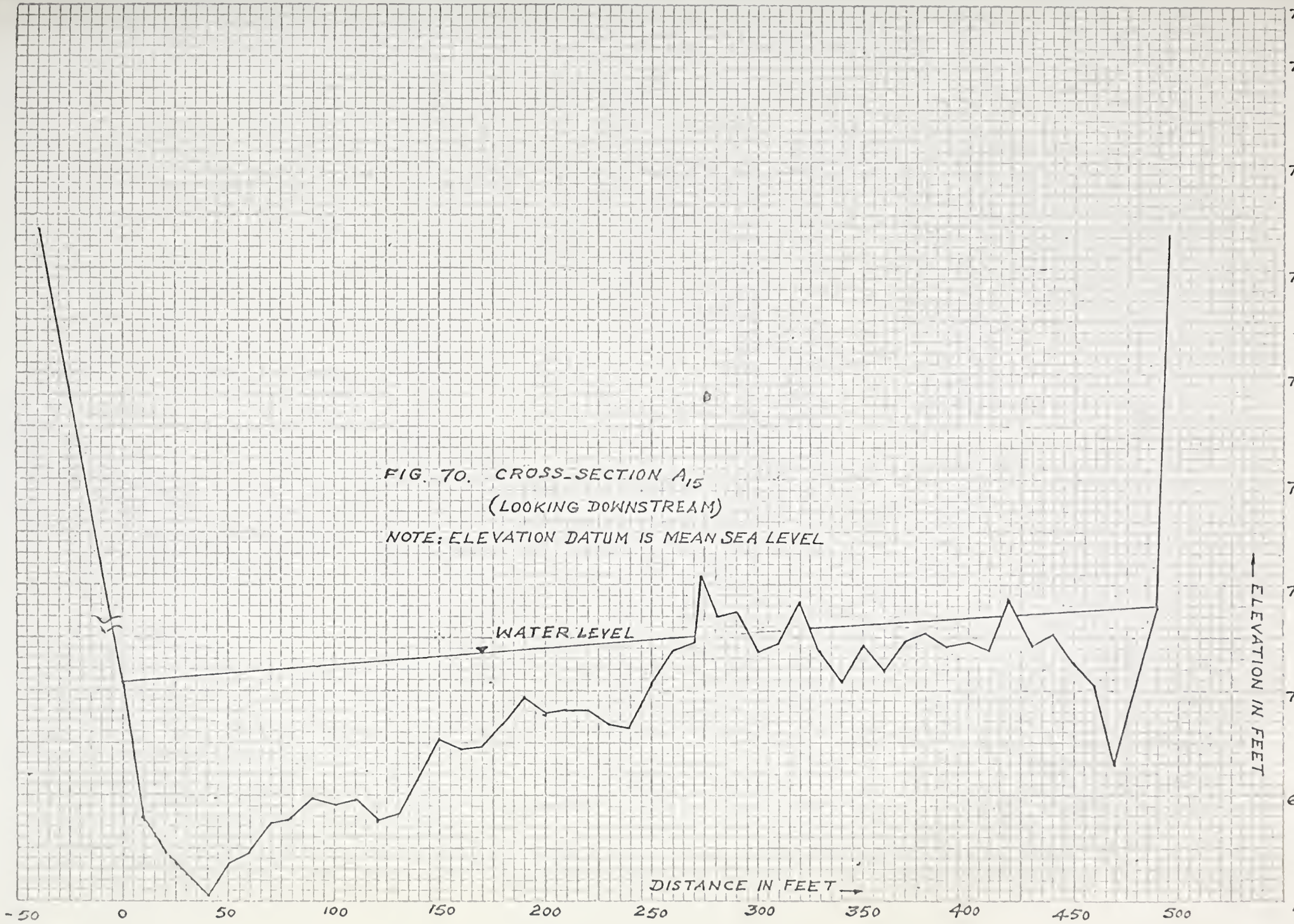


FIG. 70. CROSS-SECTION A_{15}
(LOOKING DOWNSTREAM)
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

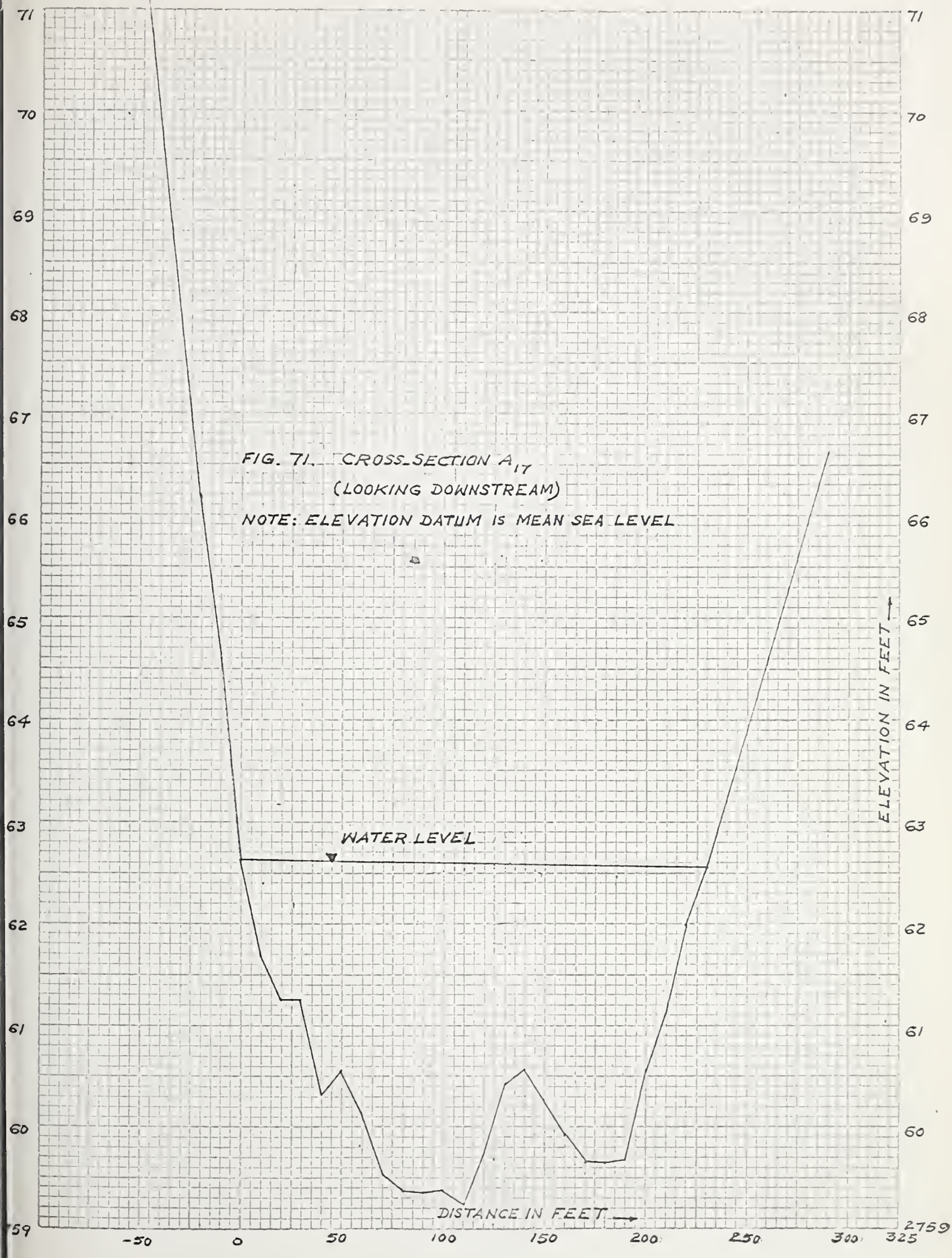


FIG. 71. CROSS-SECTION A_{17}
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

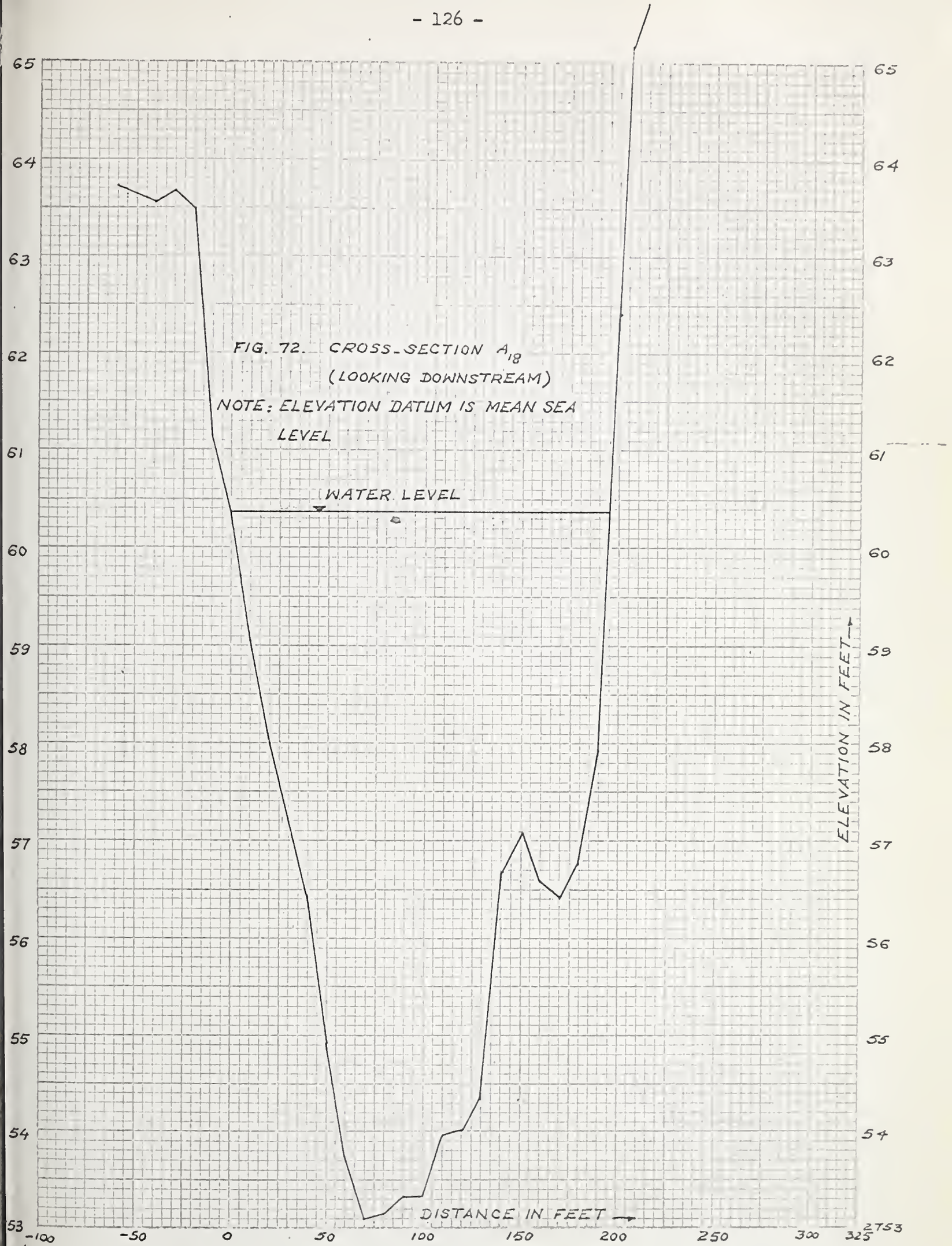


FIG. 72. CROSS-SECTION A_{18}
(LOOKING DOWNSTREAM)
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

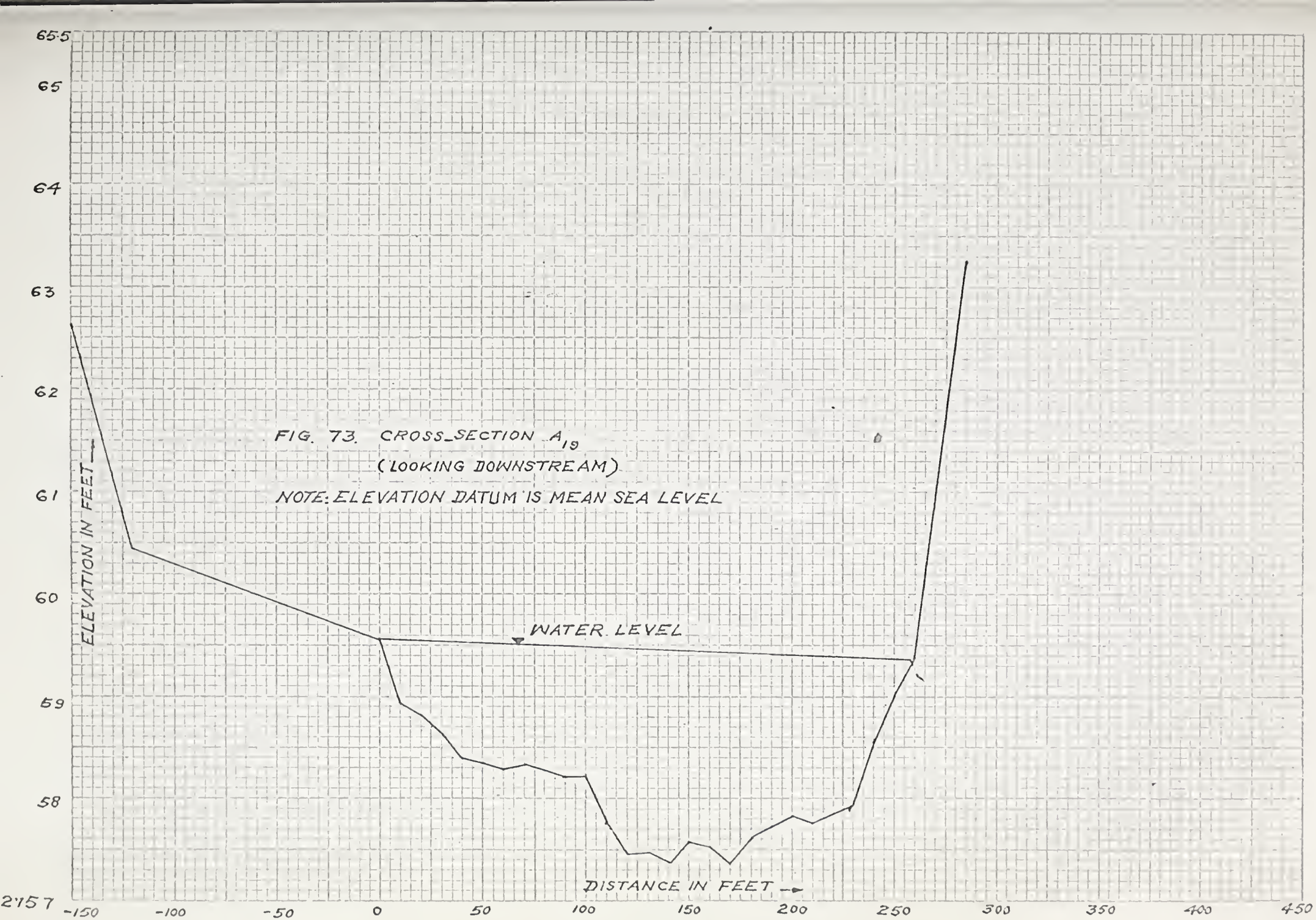


FIG. 73. CROSS_SECTION A_{19}
(LOOKING DOWNSTREAM)
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

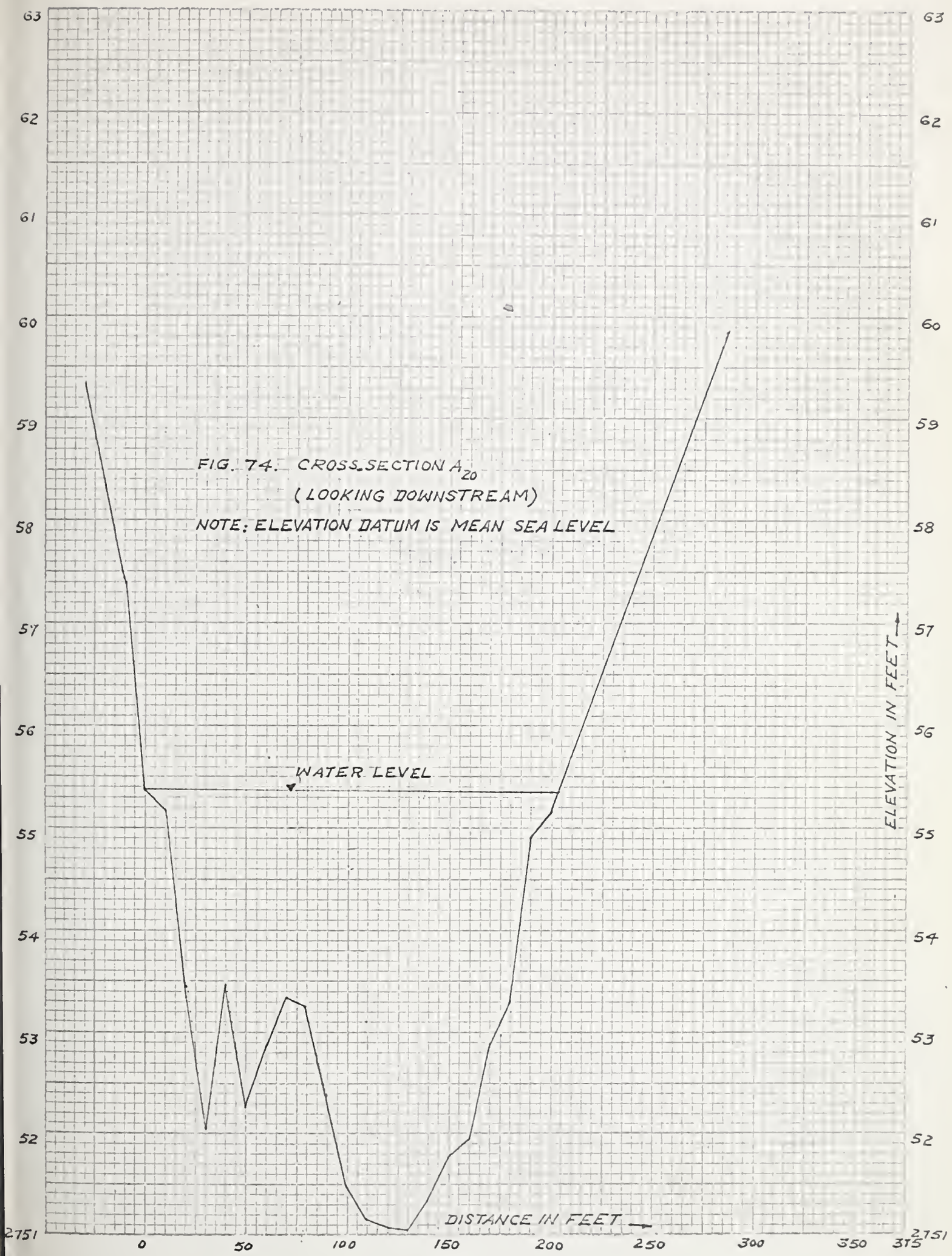


FIG. 74. CROSS SECTION A_{20}
(LOOKING DOWNSTREAM)
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

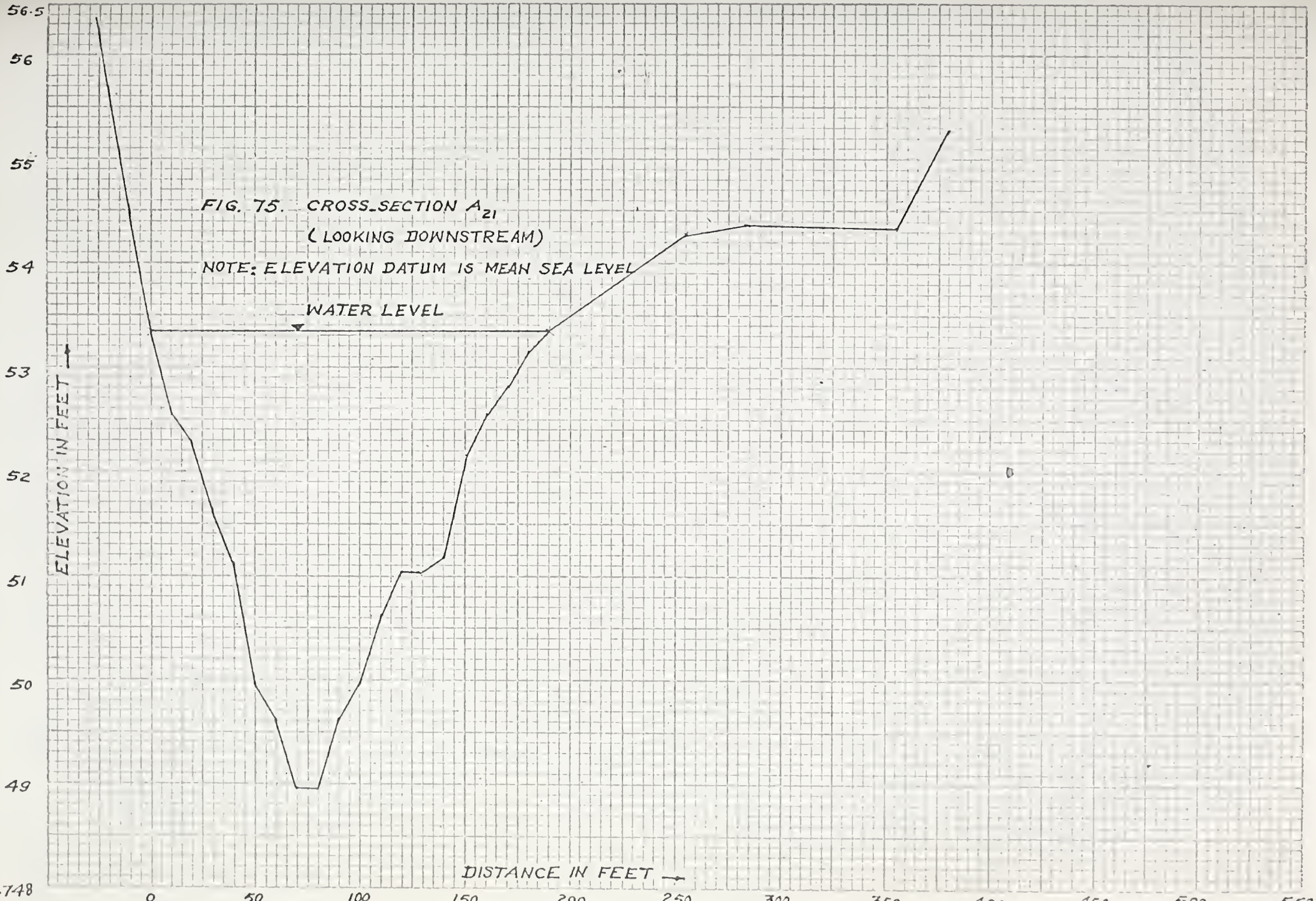


FIG. 75. CROSS-SECTION A_{21}
(LOOKING DOWNSTREAM)
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

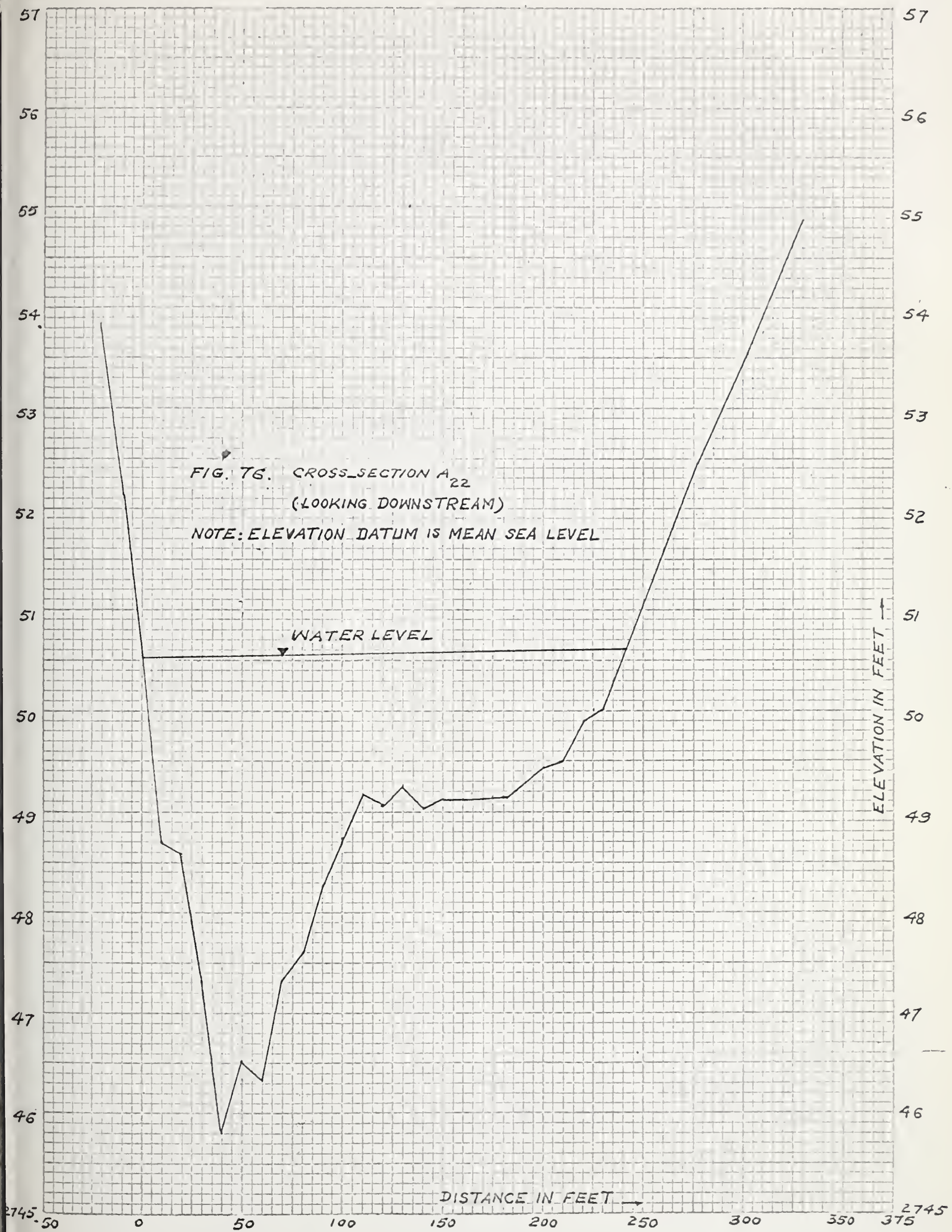


FIG. 76. CROSS-SECTION A_{22}
(LOOKING DOWNSTREAM)
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

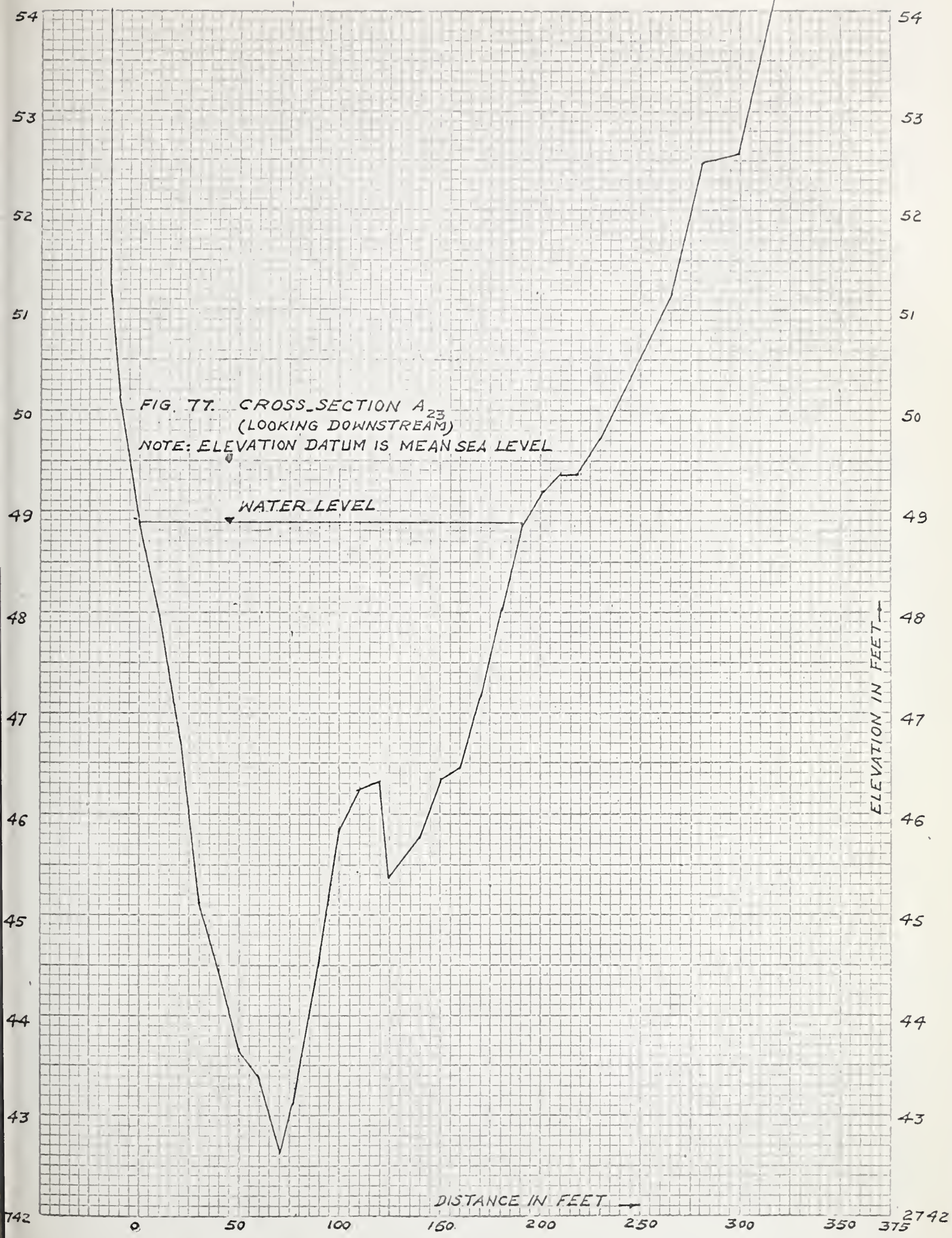
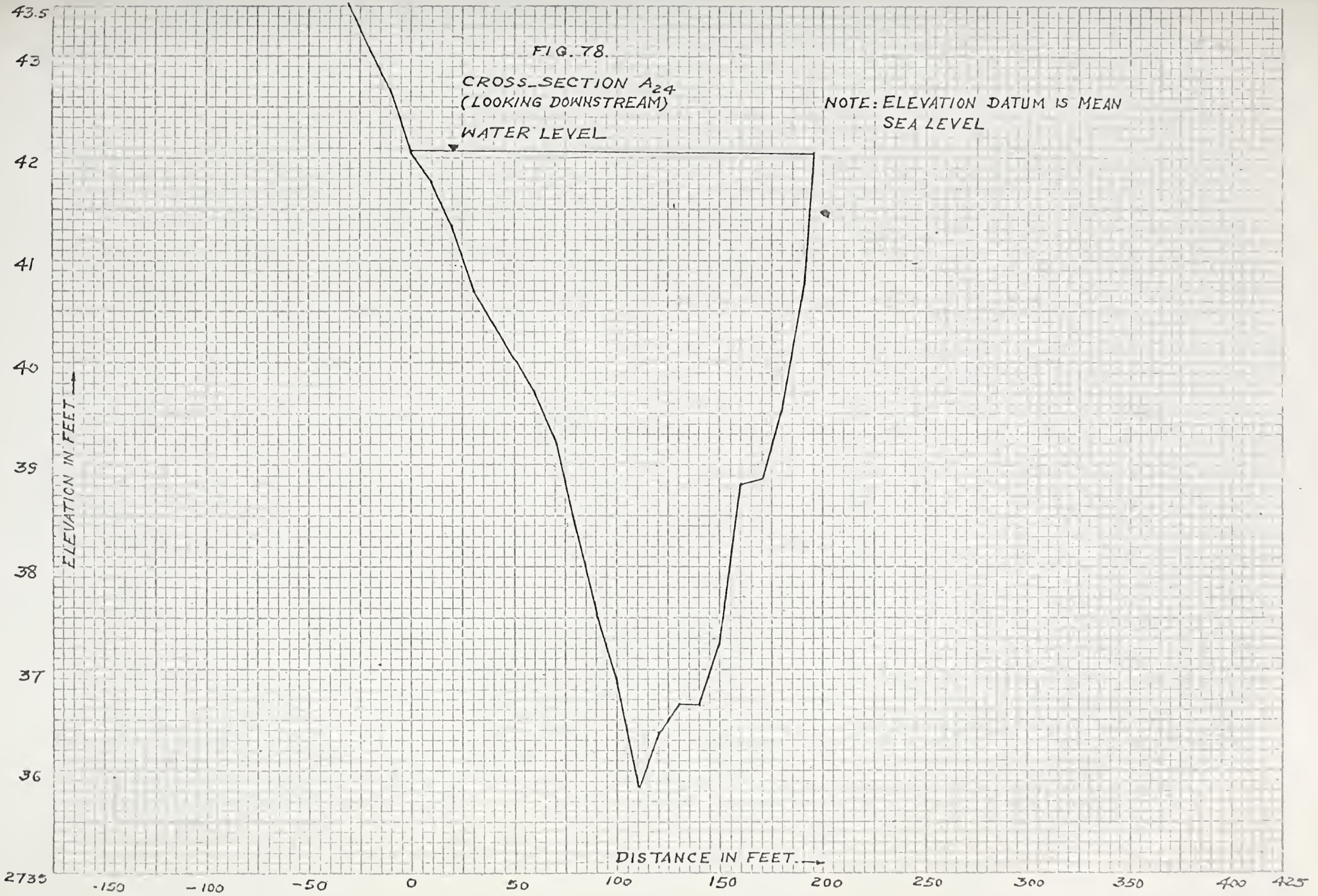


FIG. 77. CROSS_SECTION A_{23}
(LOOKING DOWNSTREAM)
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL


FIG. 78.
CROSS-SECTION A_{24}
(LOOKING DOWNSTREAM)
WATER LEVEL
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
ELEVATION IN FEET
DISTANCE IN FEET
43.5
43
42
41
40
39
38
37
36
2735
-150
-100
-50
0
50
100
150
200
250
300
350
400
425

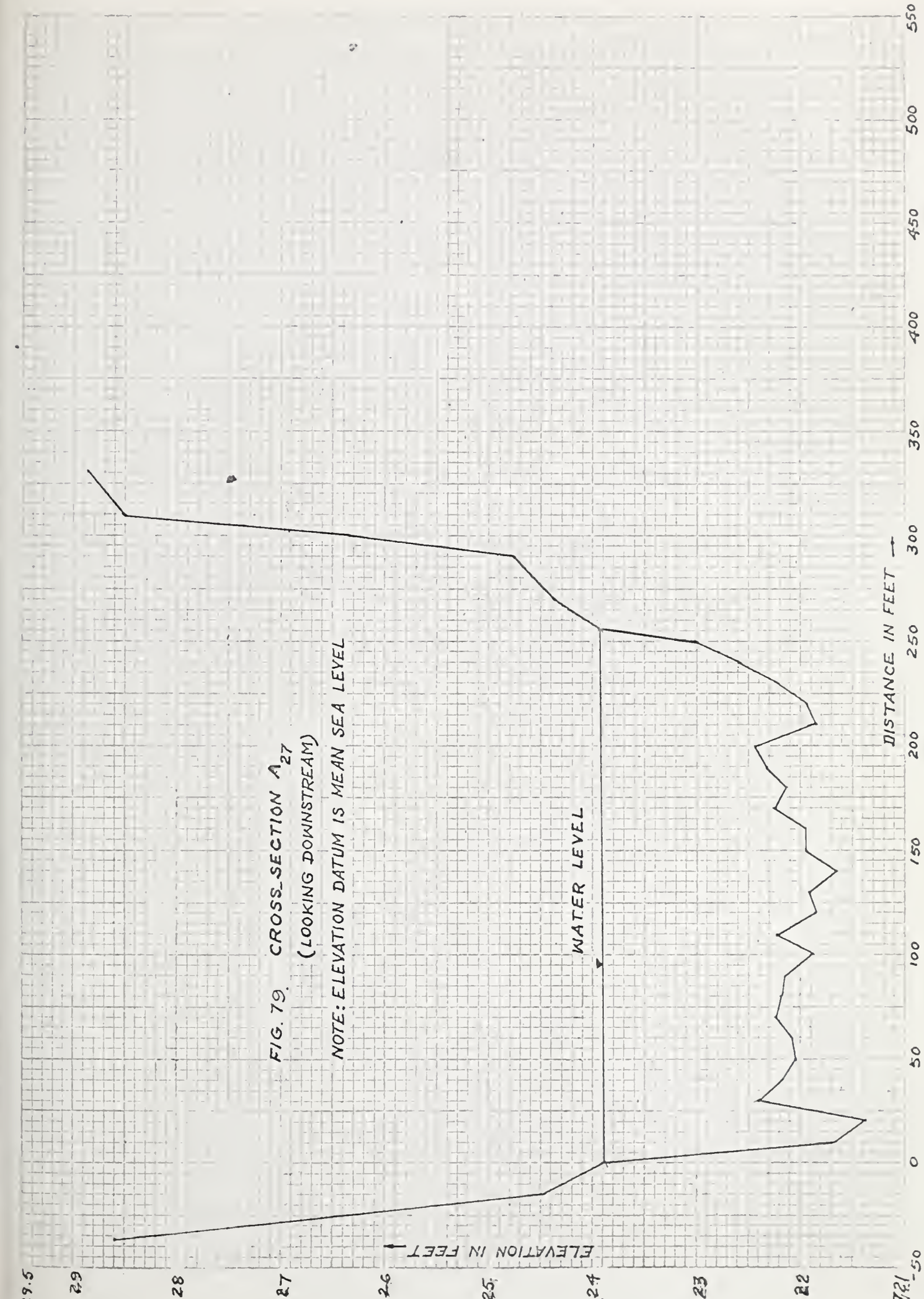


FIG. 79. CROSS_SECTION A_{27} (LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

27121

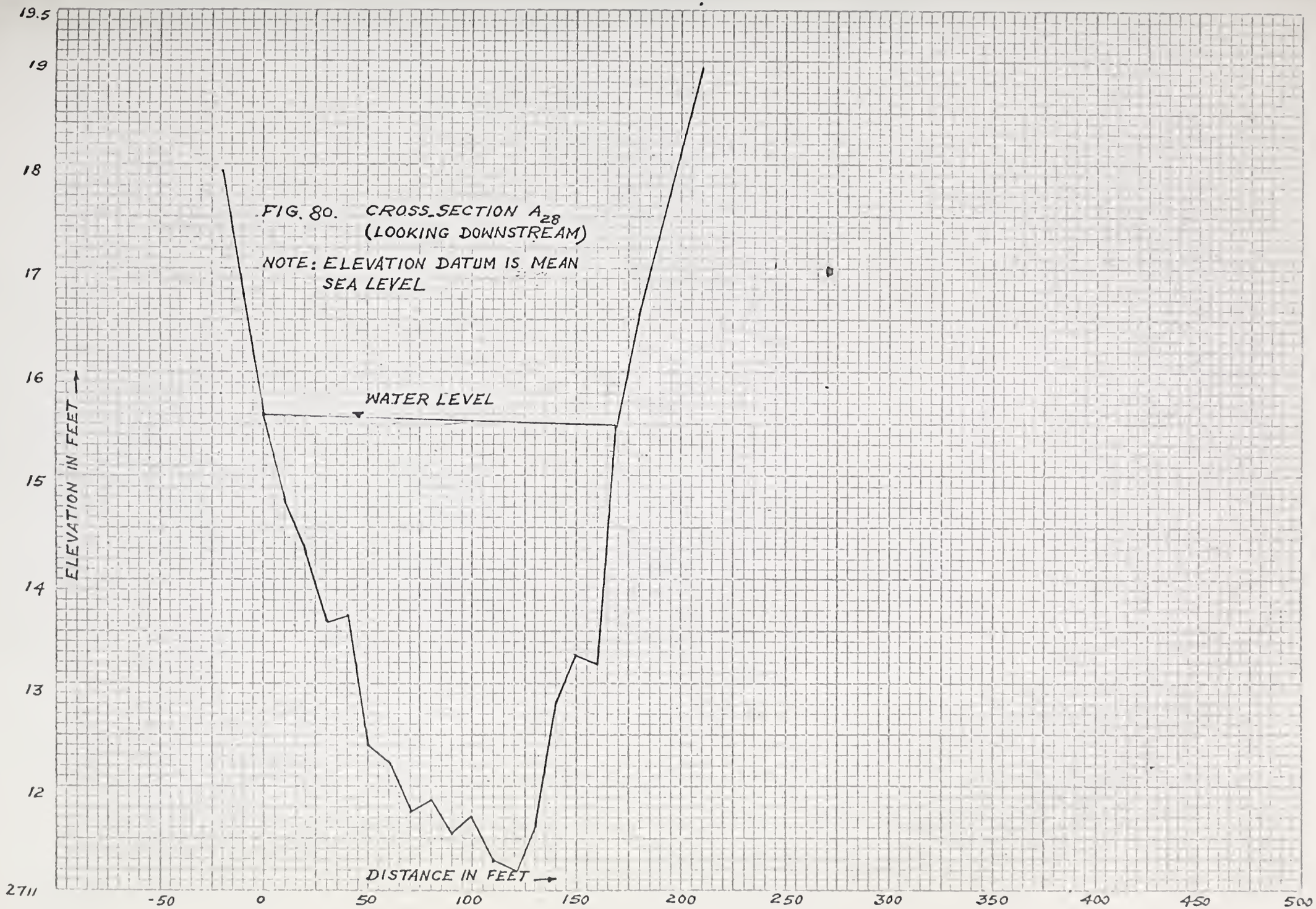


FIG. 80. CROSS-SECTION A_{28} (LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

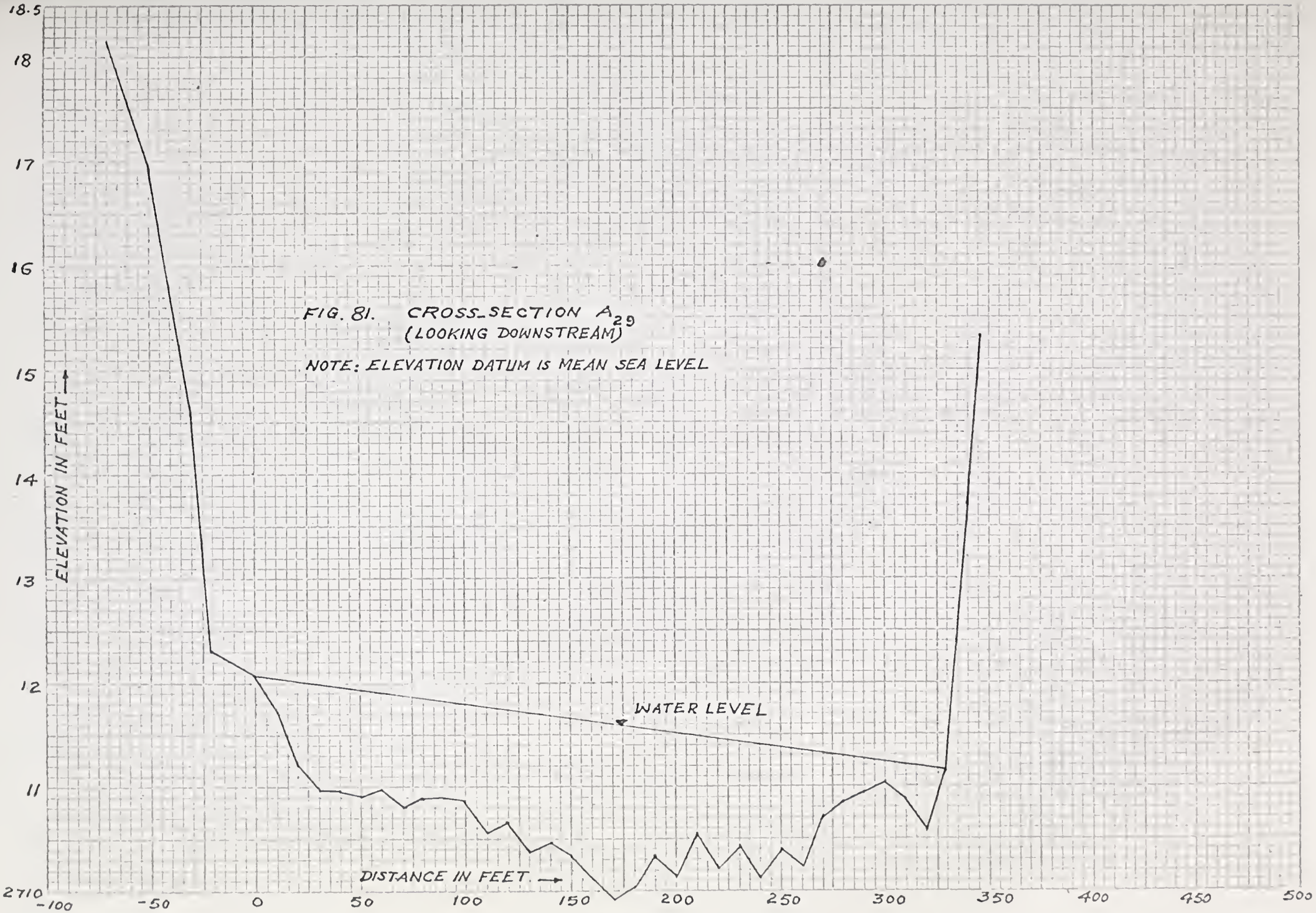


FIG. 81. CROSS-SECTION A_{29}
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

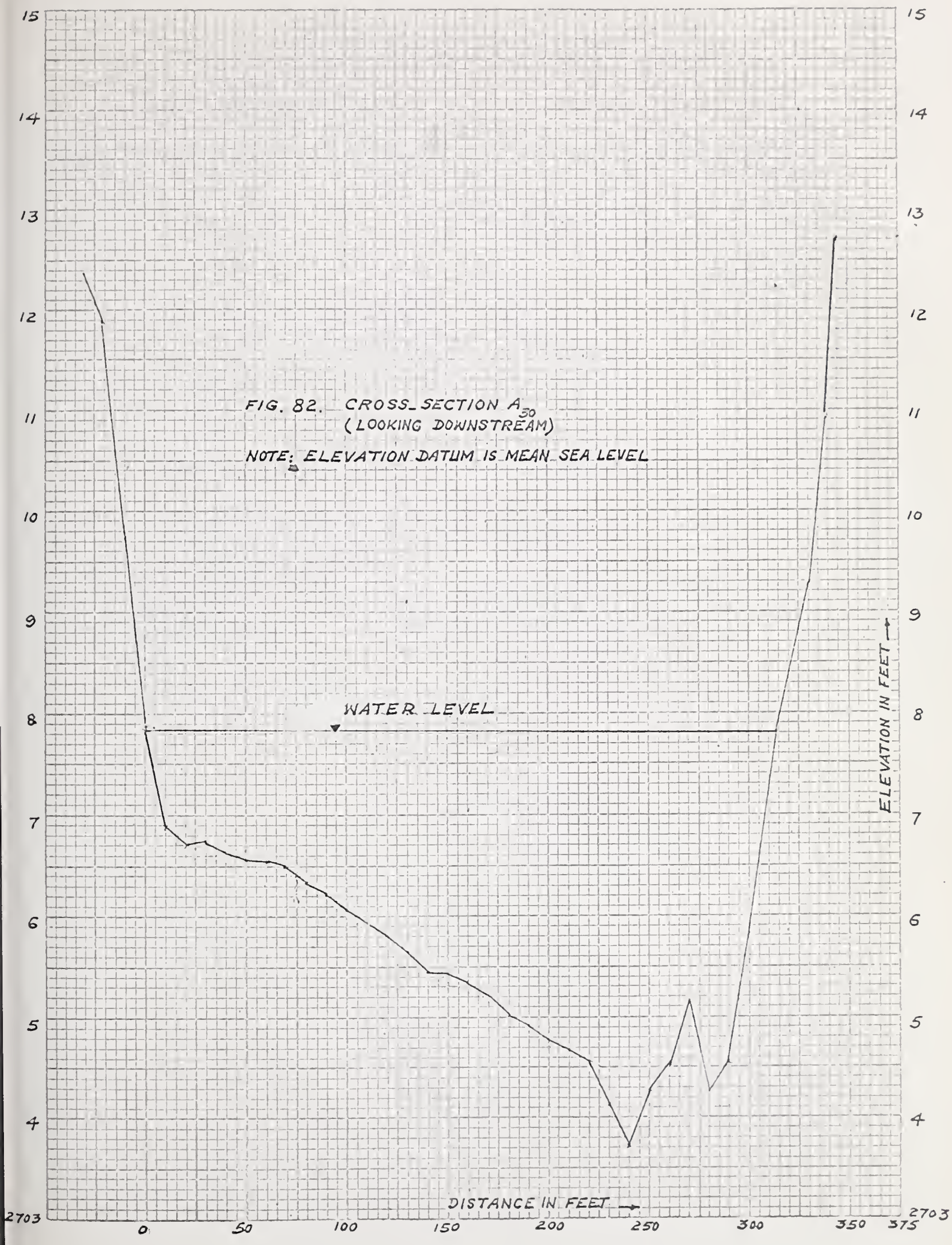


FIG. 82. CROSS-SECTION A_{30}
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

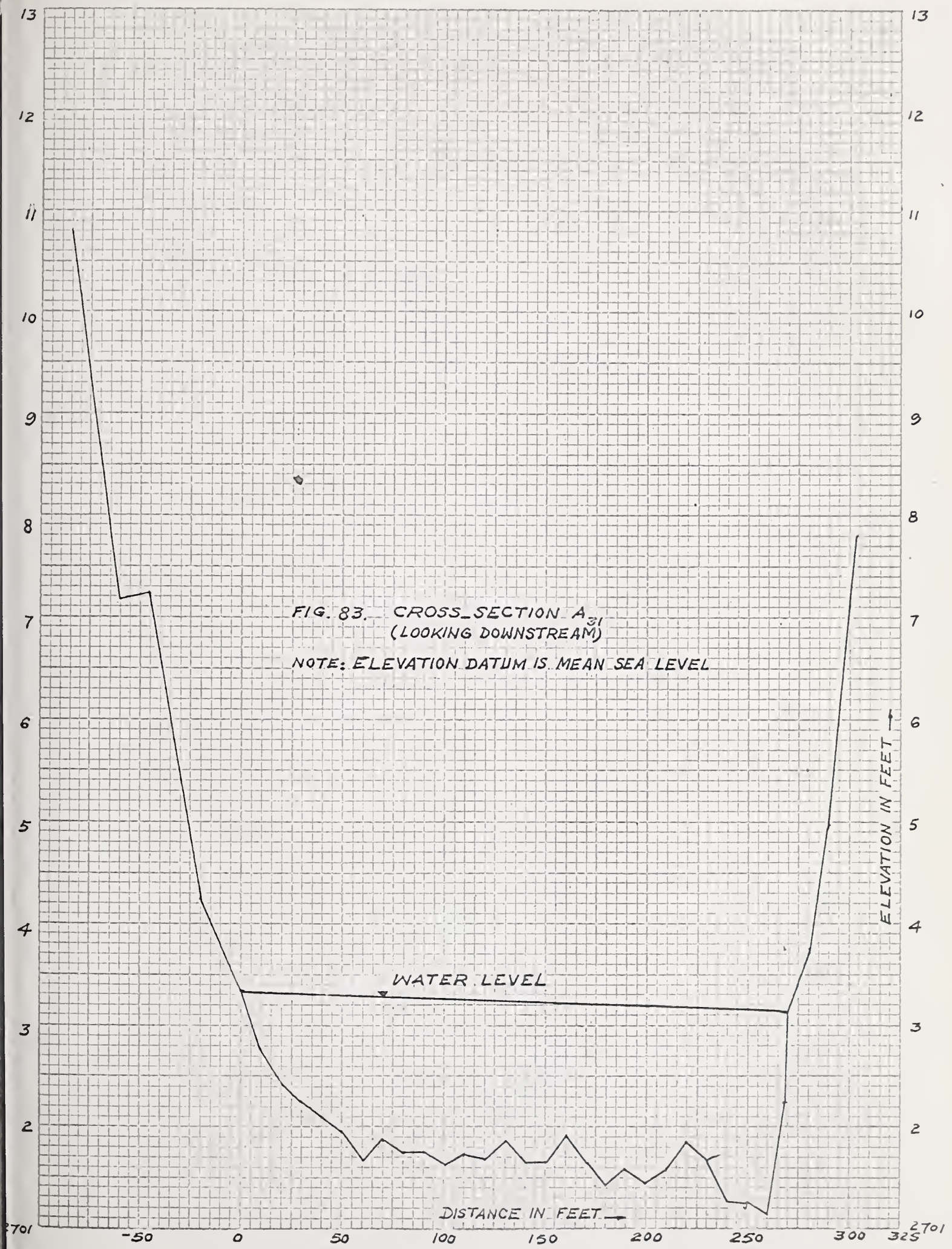


FIG. 83. CROSS-SECTION A_{31}
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

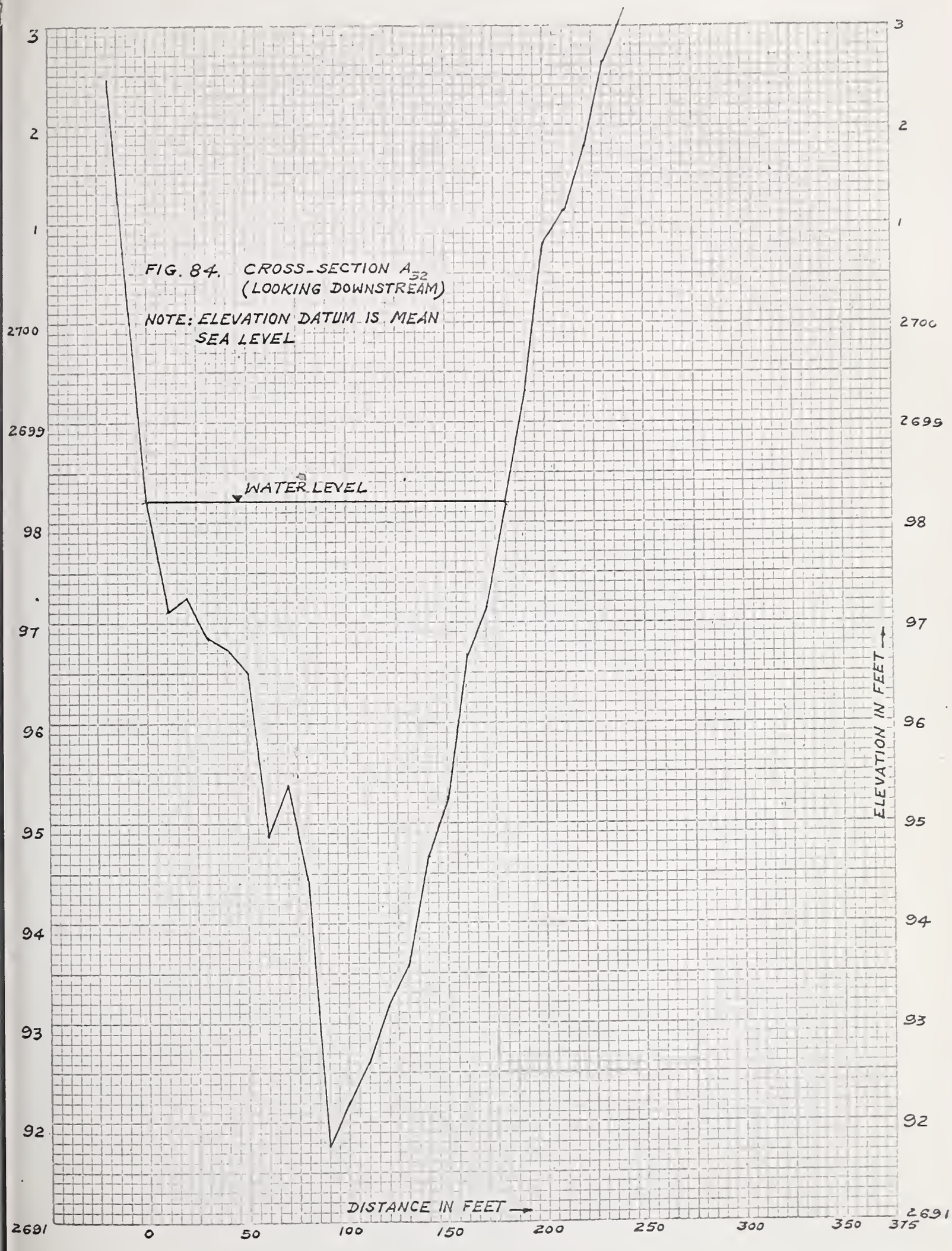


FIG. 84. CROSS-SECTION A_{32} (LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

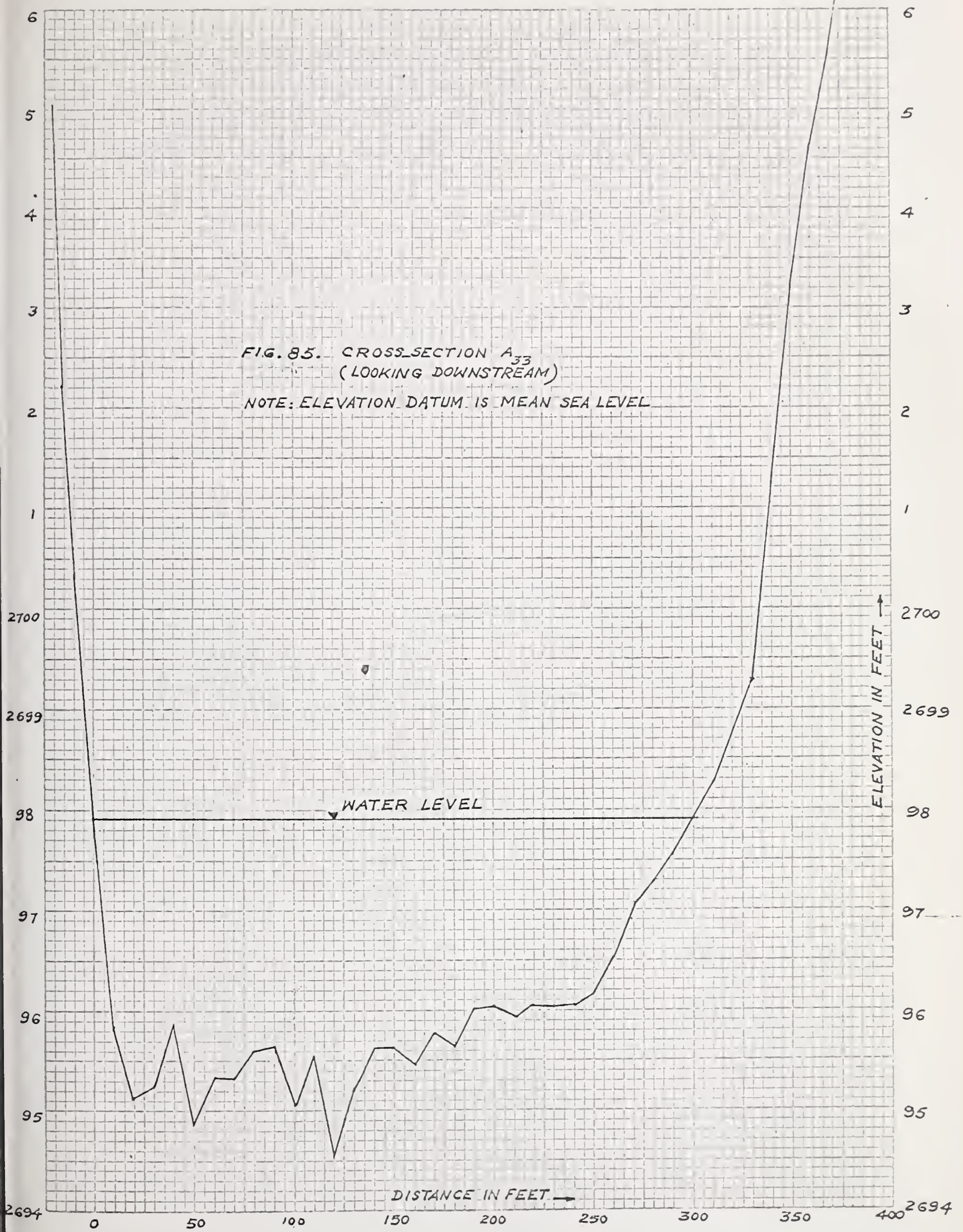


FIG. 85. CROSS-SECTION A_{33} (LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

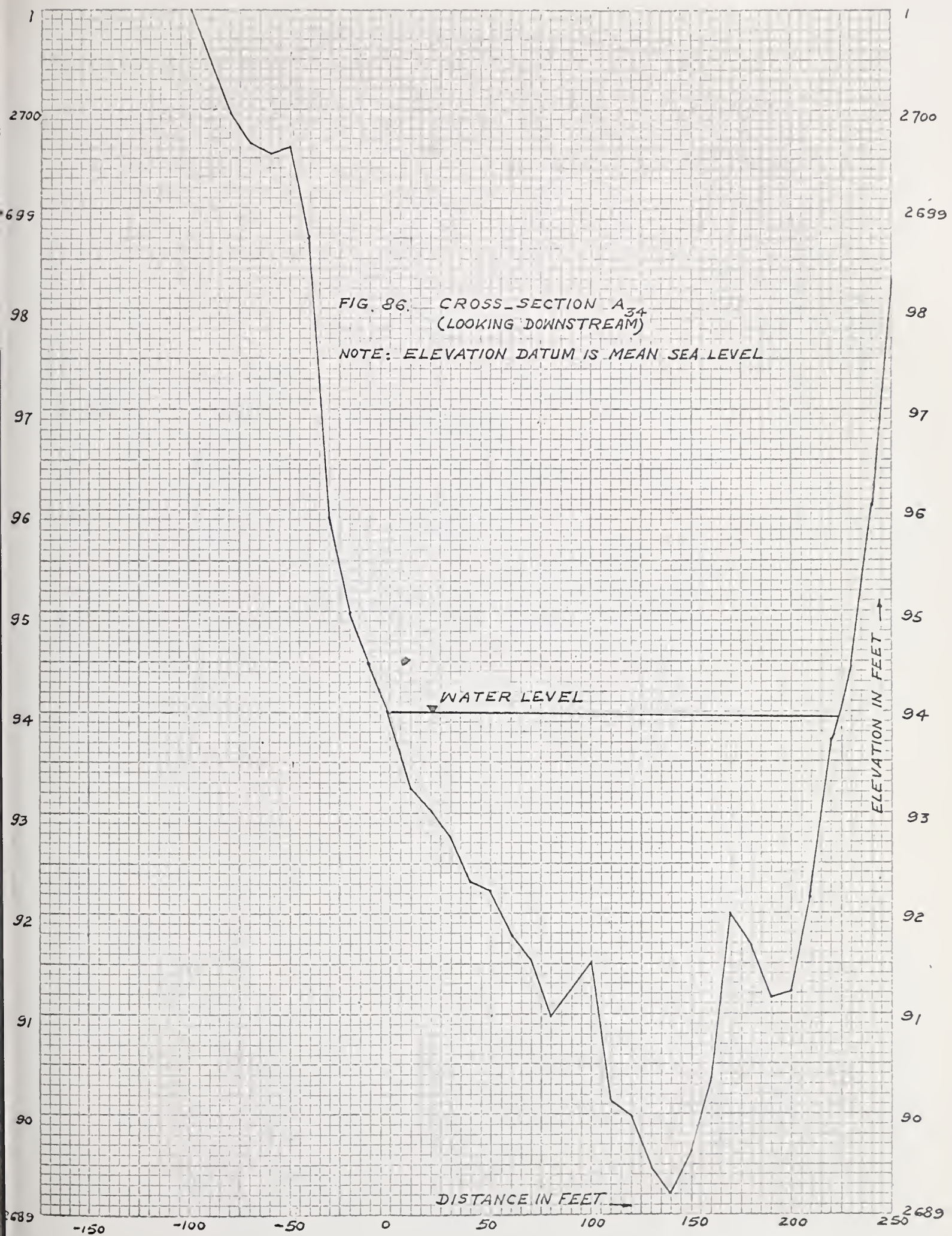


FIG. 86. CROSS-SECTION A_{34}
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

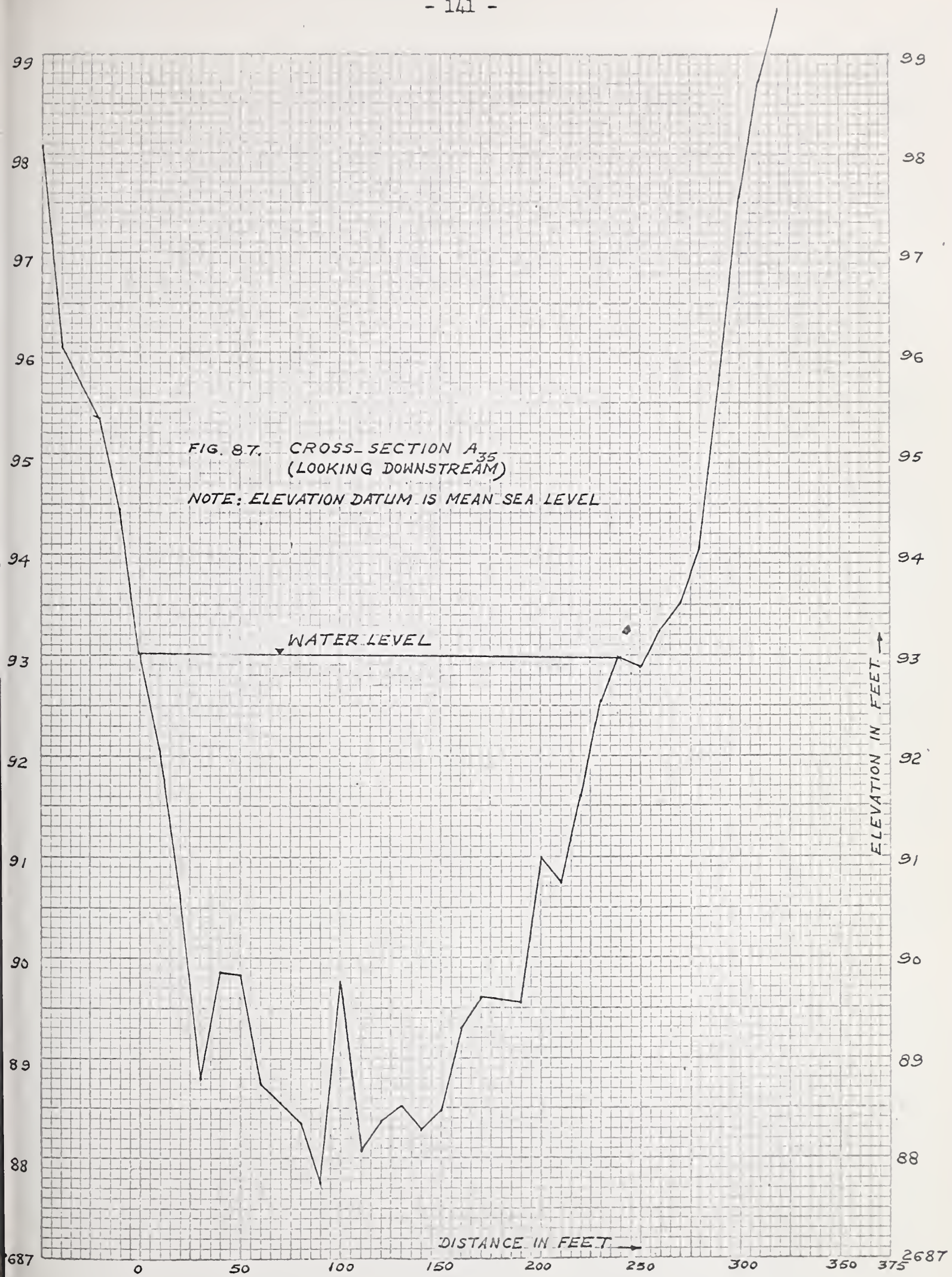


FIG. 87. CROSS-SECTION A_{35}
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

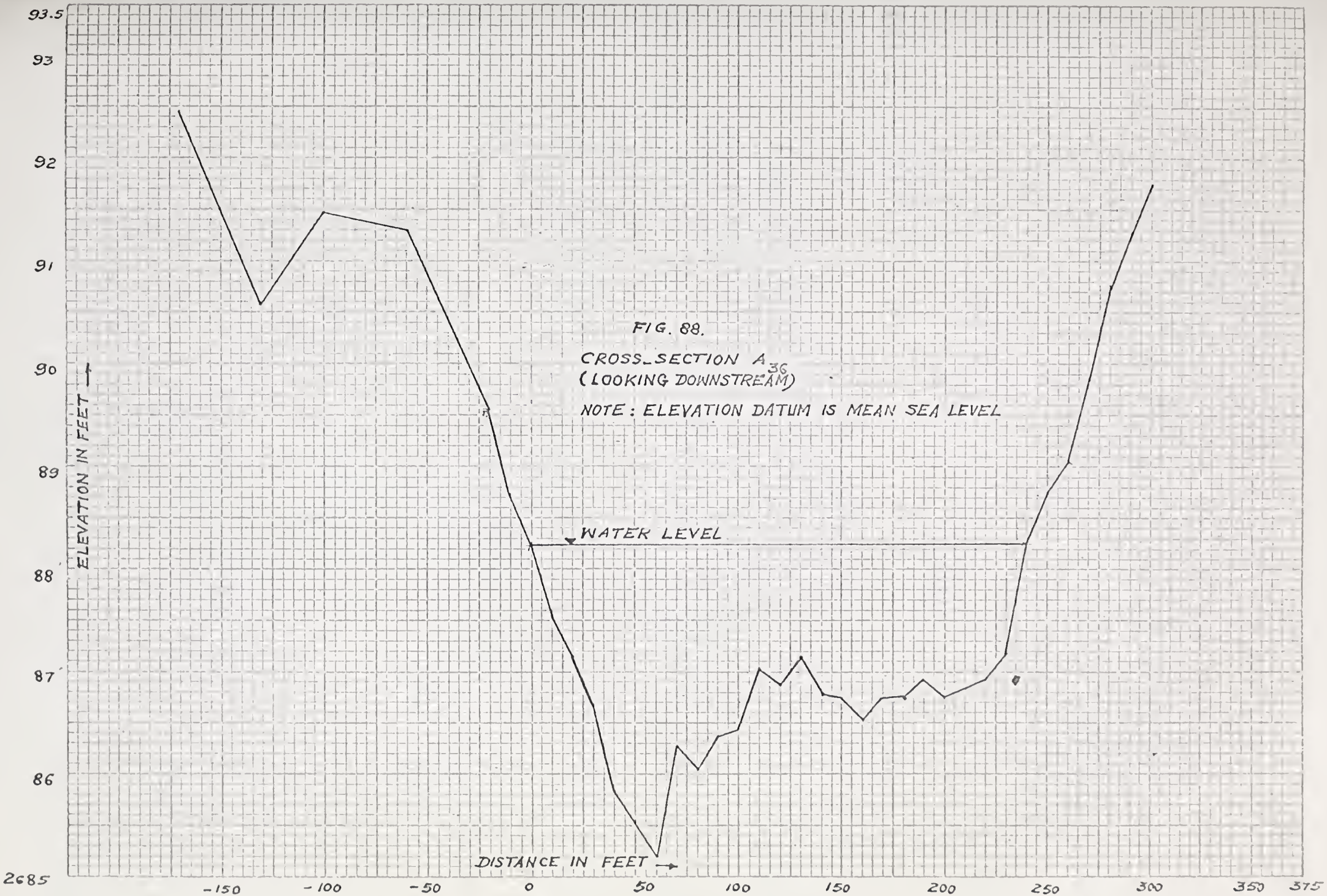


FIG. 88.

CROSS-SECTION A[36]
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

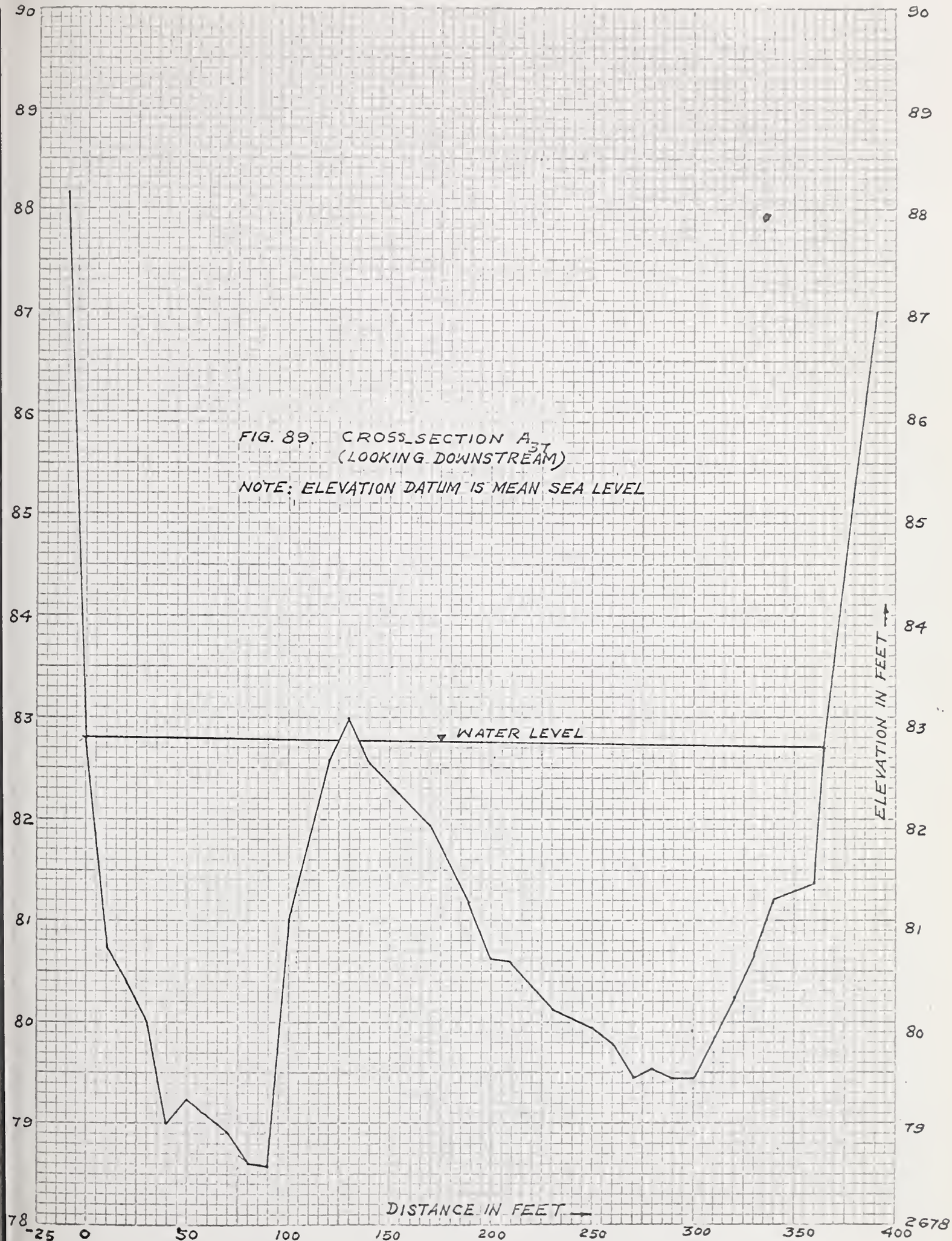


FIG. 89. CROSS-SECTION A_{3T}
(LOOKING DOWNSTREAM)

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

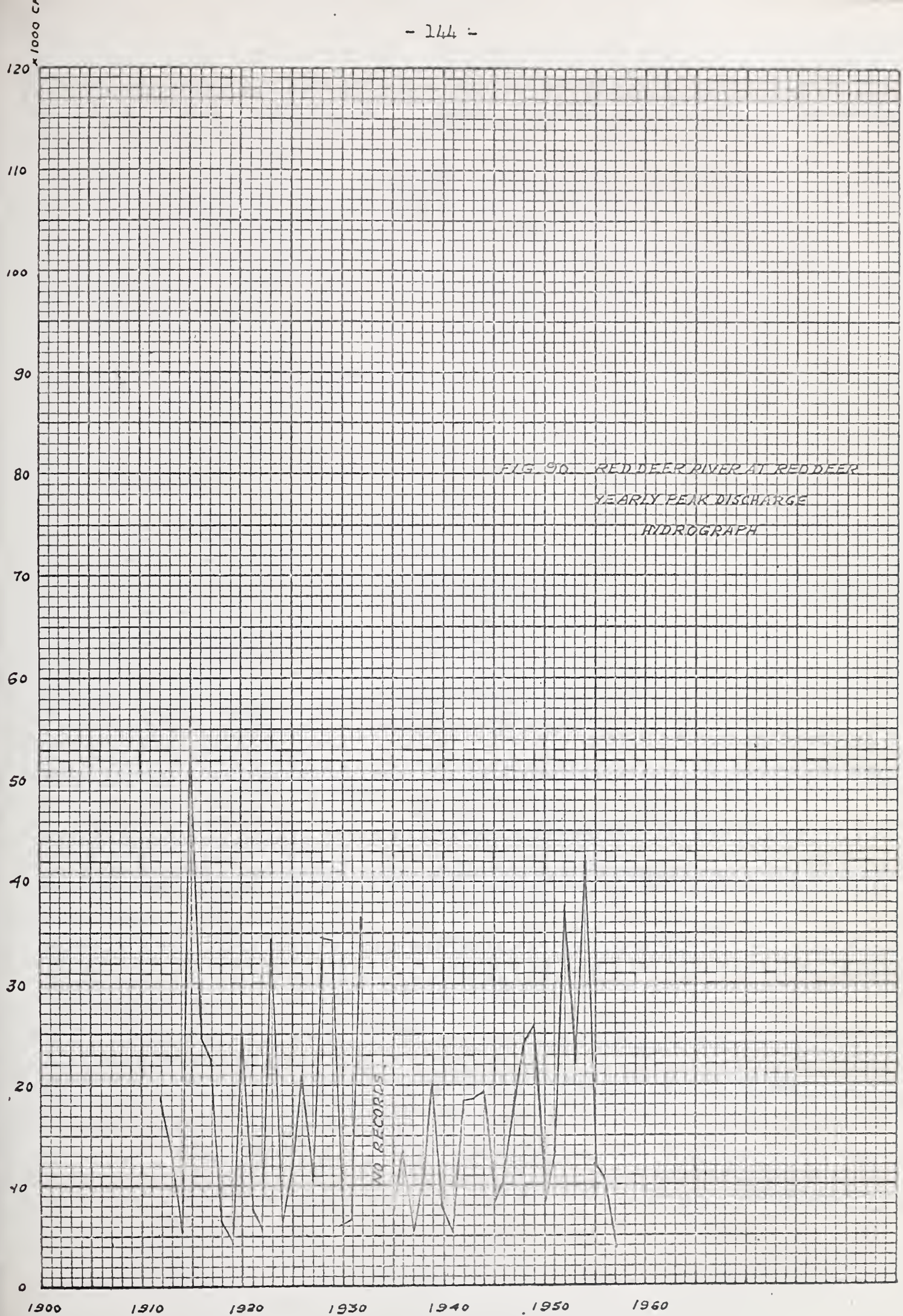


FIG. 90. RED DEER RIVER AT RED DEER
YEARLY PEAK DISCHARGE
HYDROGRAPH

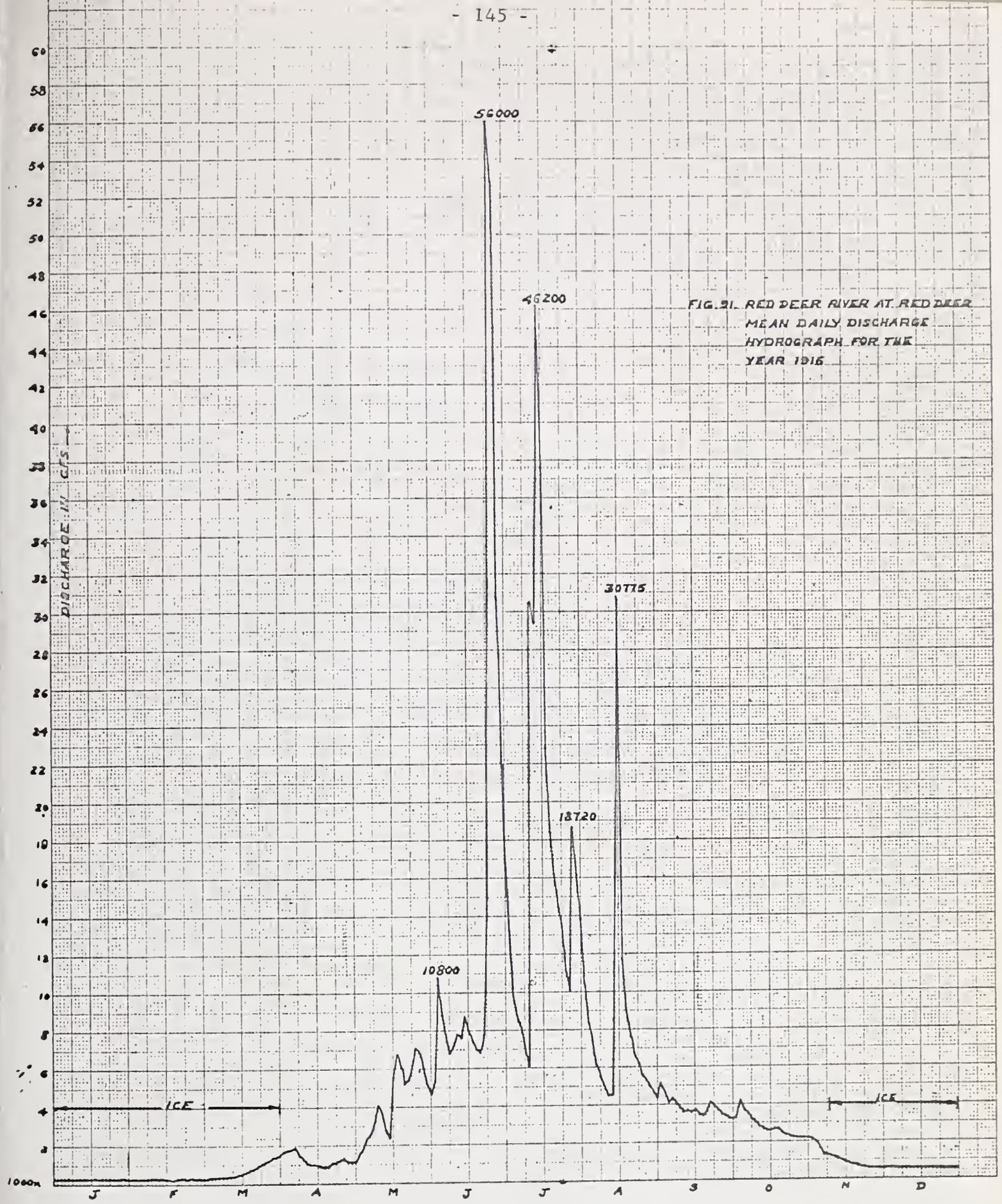


FIG. 21. RED DEER RIVER AT RED DEER
MEAN DAILY DISCHARGE
HYDROGRAPH FOR THE
YEAR 1916

- 145 -

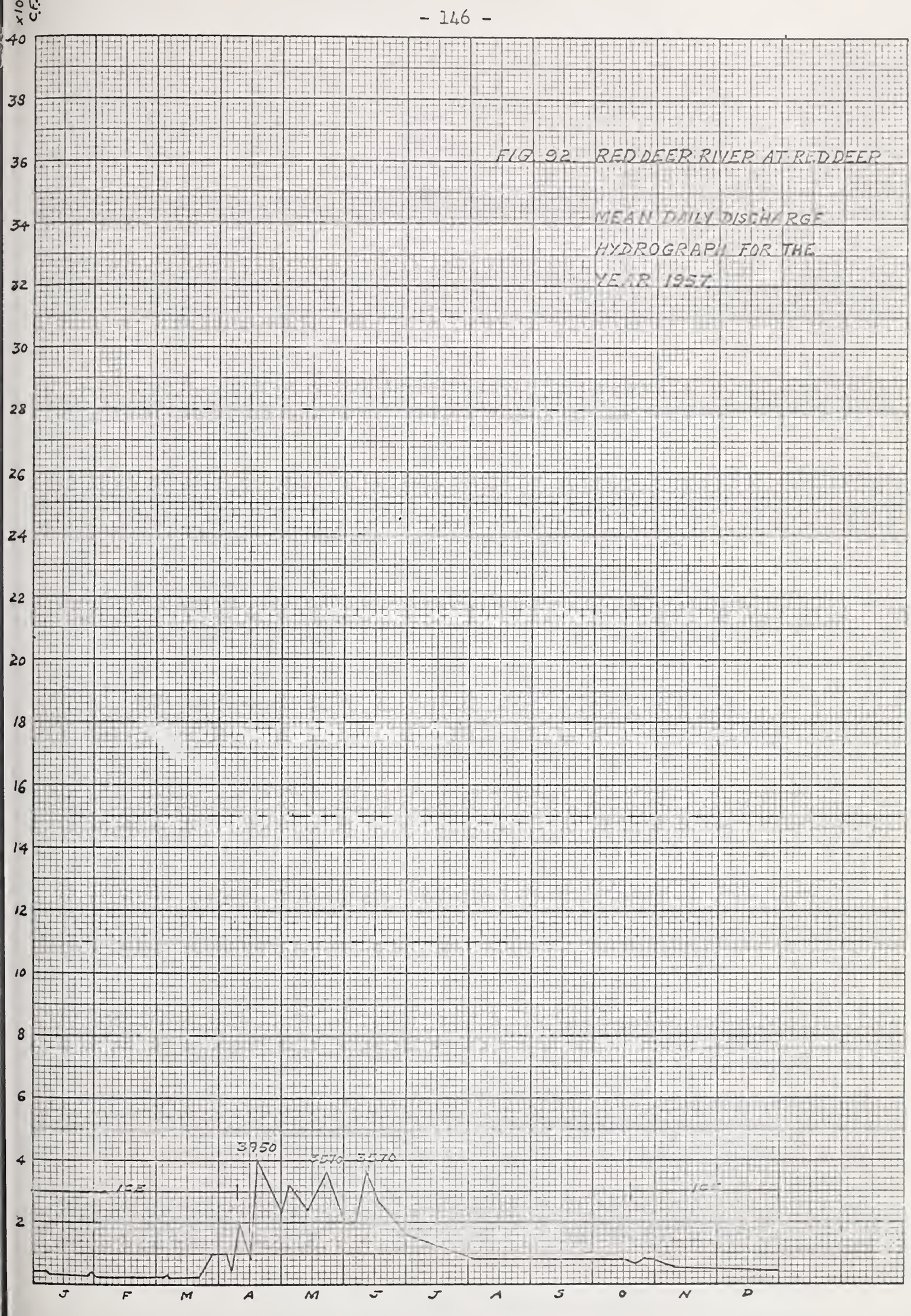


FIG. 92. RED DEER RIVER AT RED DEER

MEAN DAILY DISCHARGE HYDROGRAPH FOR THE YEAR 1957.

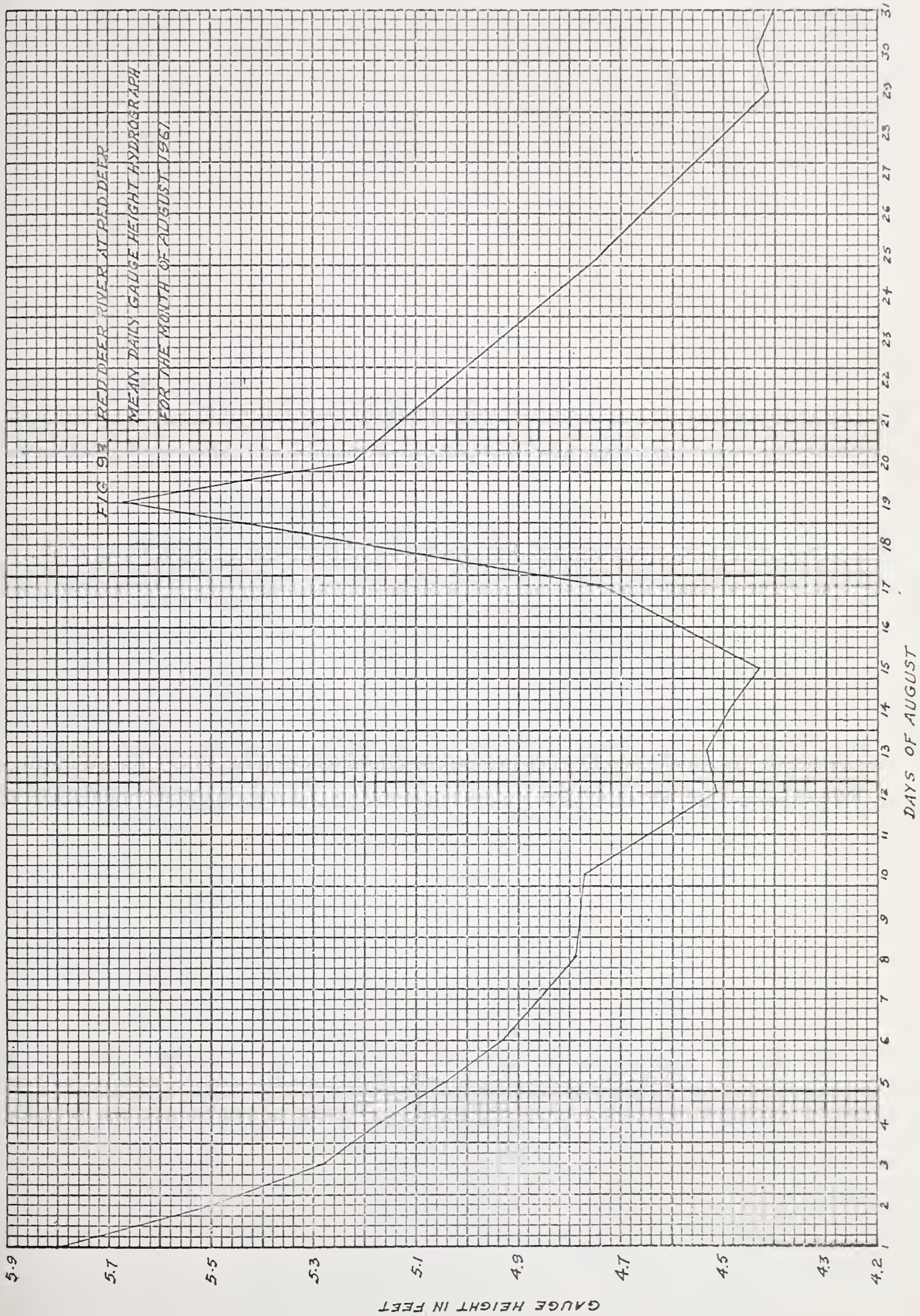
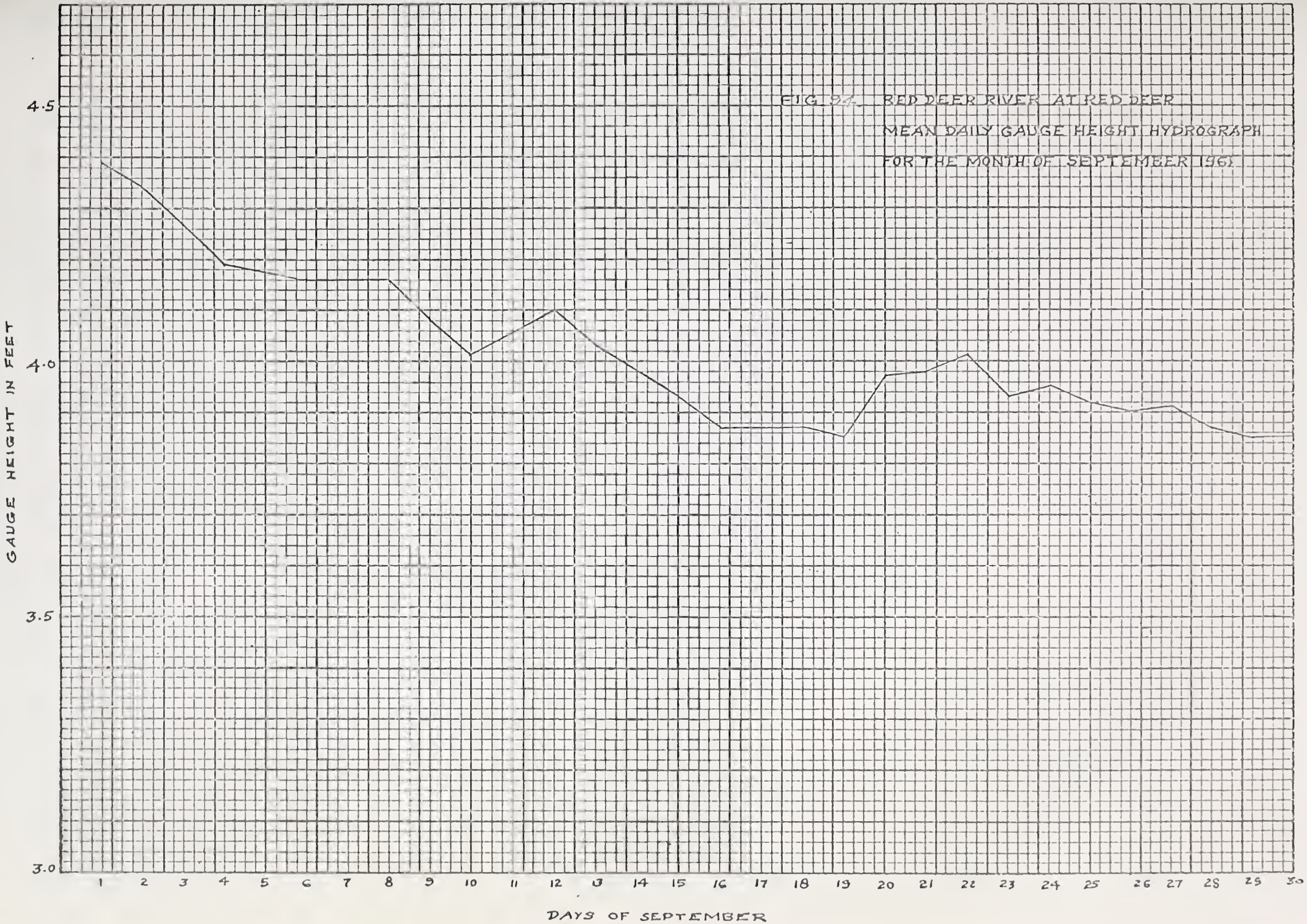
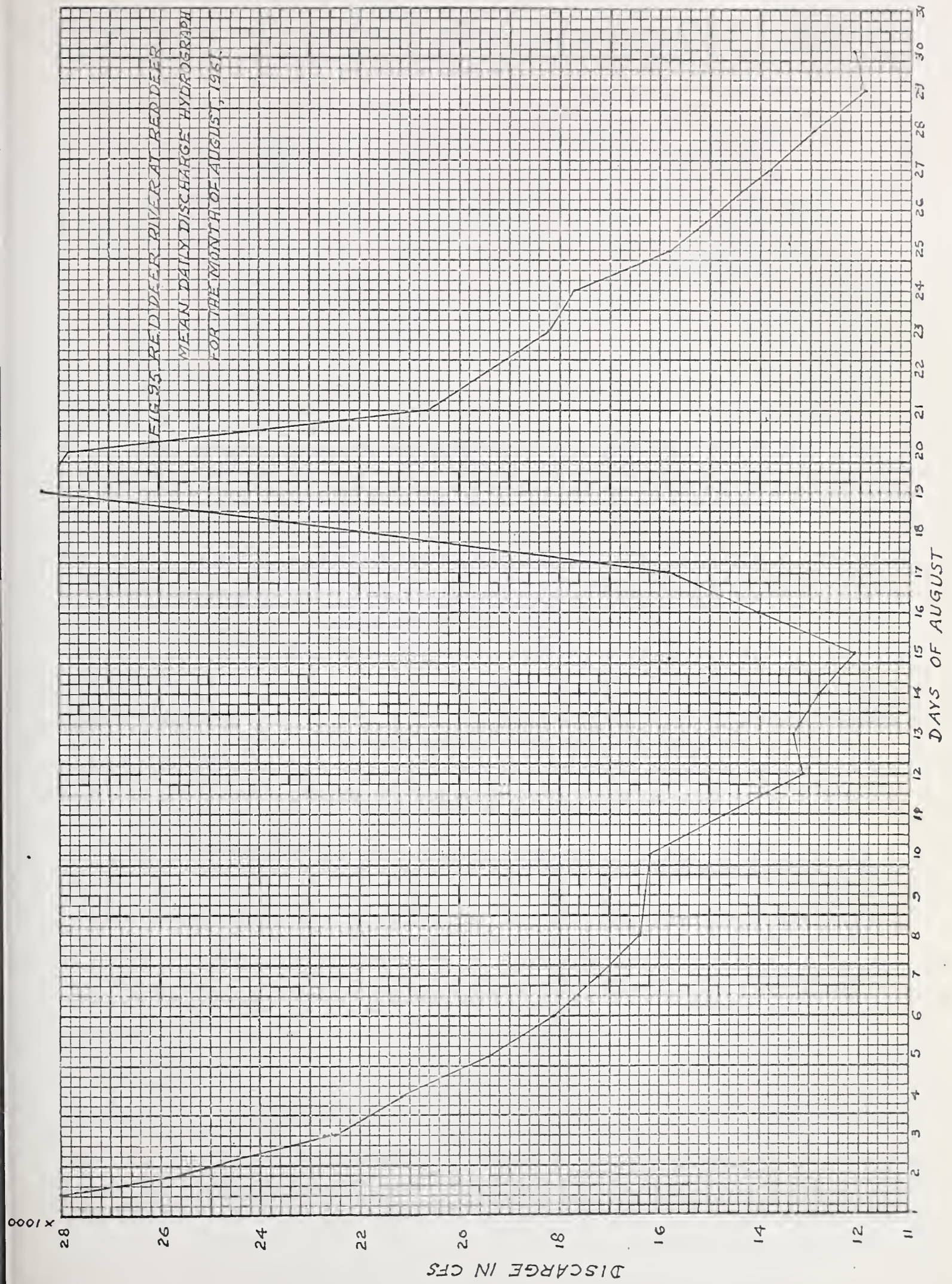


FIG 93. REINDEER RIVER AT REINDEER
MEAN DAILY GAUGE HEIGHT HYDROGRAPH
FOR THE MONTH OF AUGUST 1961


FIG. 94 RED DEER RIVER AT RED DEER
MEAN DAILY GAUGE HEIGHT HYDROGRAPH
FOR THE MONTH OF SEPTEMBER 1961
GAUGE HEIGHT IN FEET
4.5
4.0
3.5
3.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
DAYS OF SEPTEMBER


FIG. 93 RED DEER RIVER AT RED DEER
MEAN DAILY DISCHARGE HYDROGRAPH
FOR THE MONTH OF AUGUST, 1951.
DISCHARGE IN CFS
x 1000
28
26
24
22
20
18
16
14
12
11
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DAYS OF AUGUST

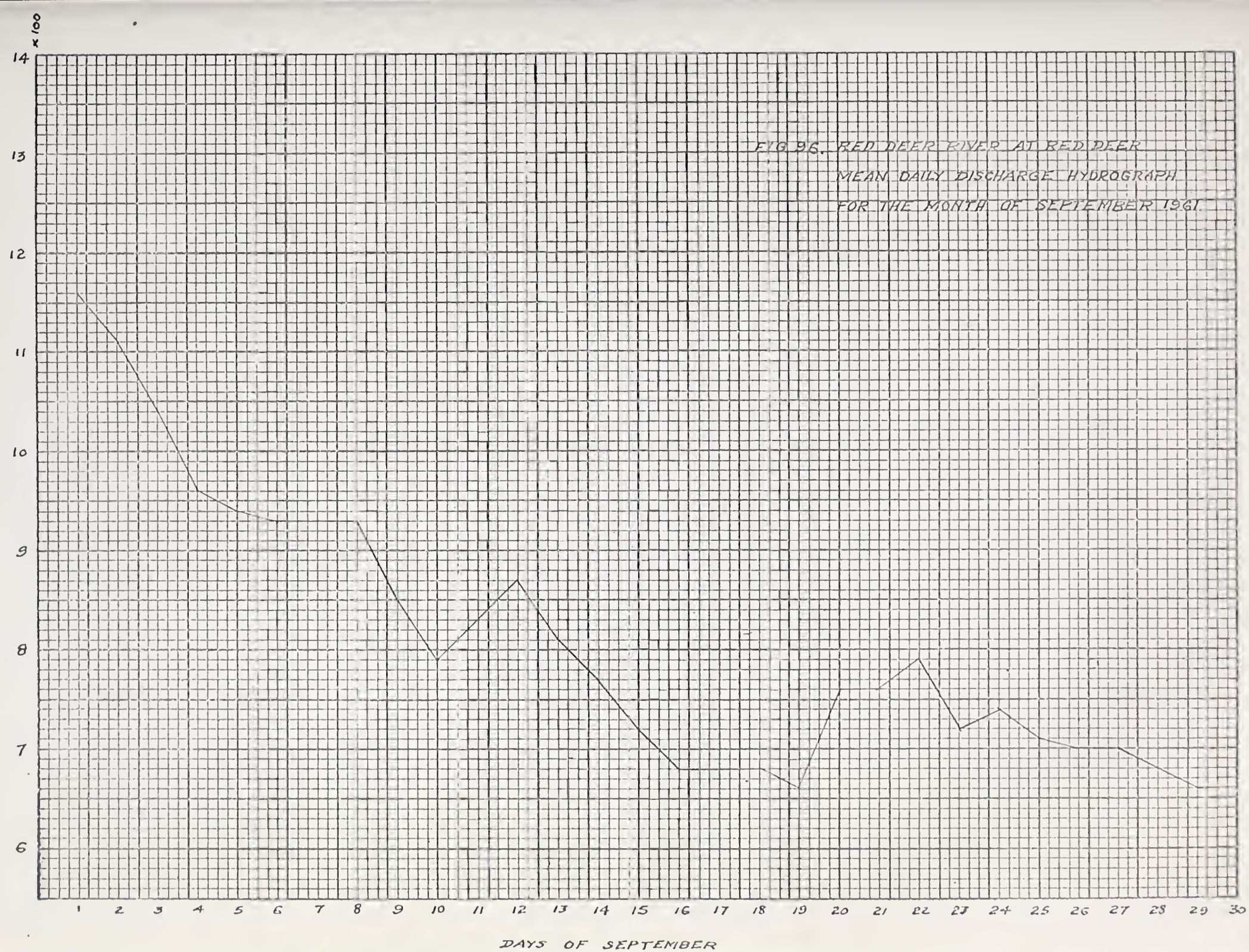
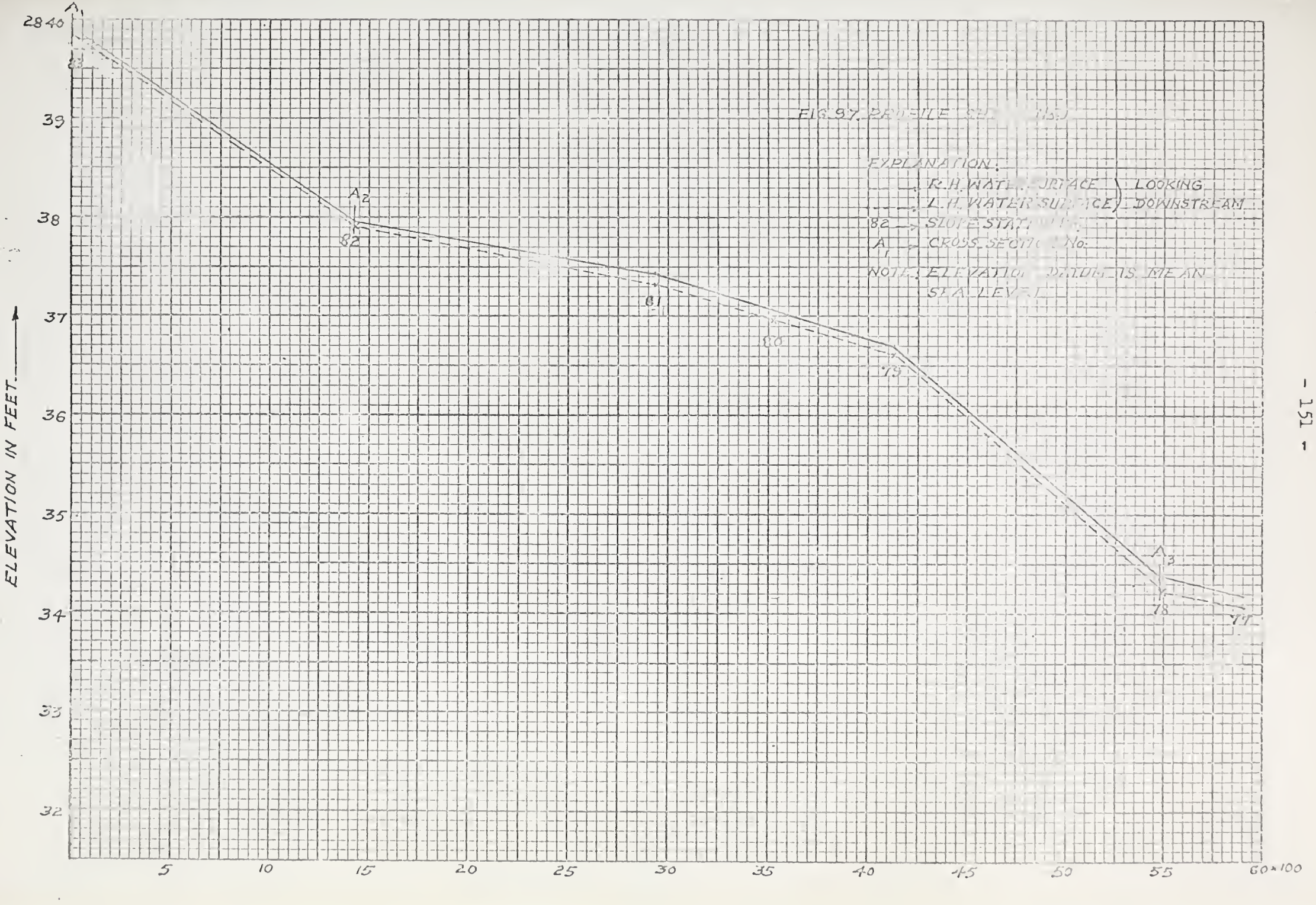
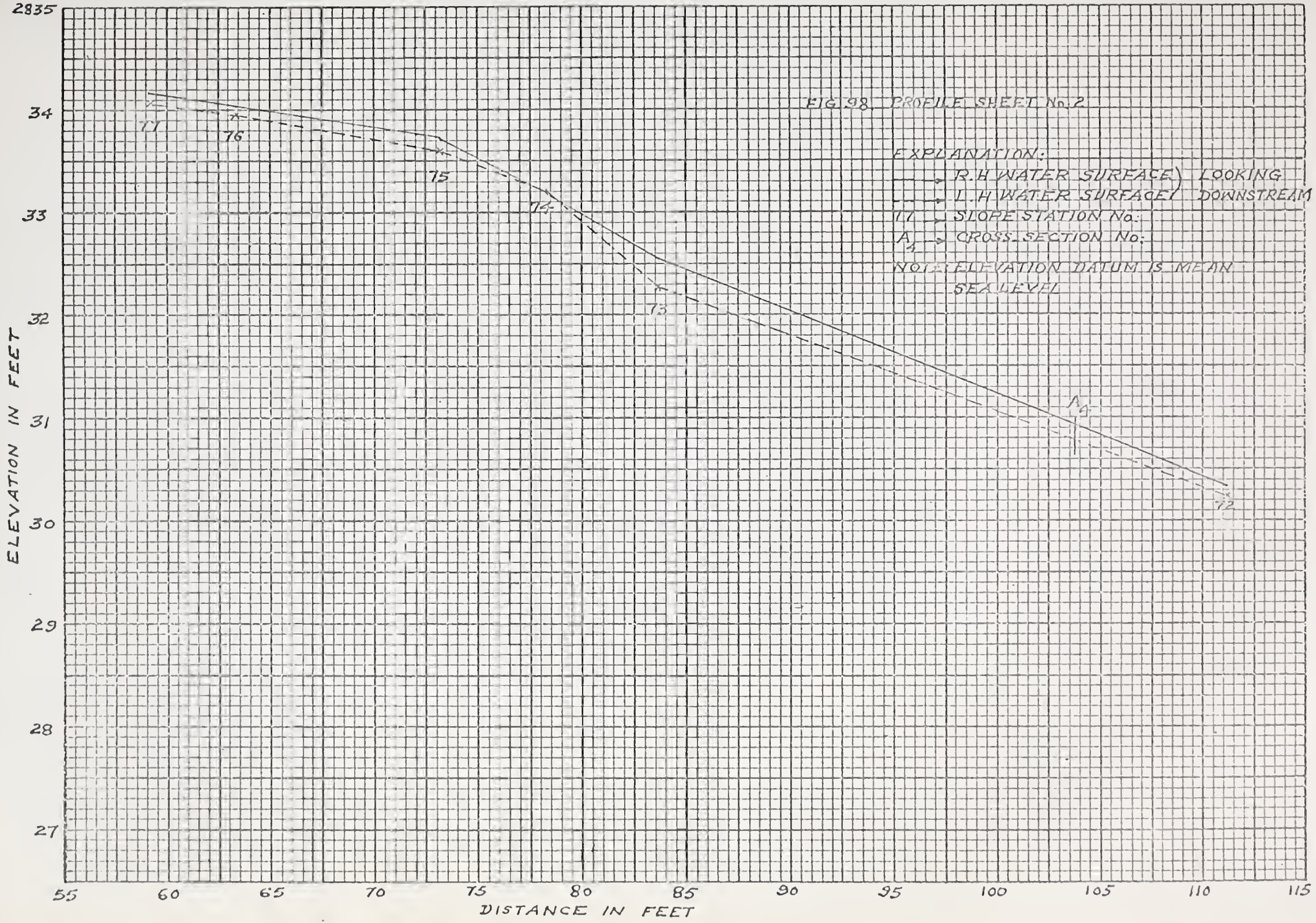
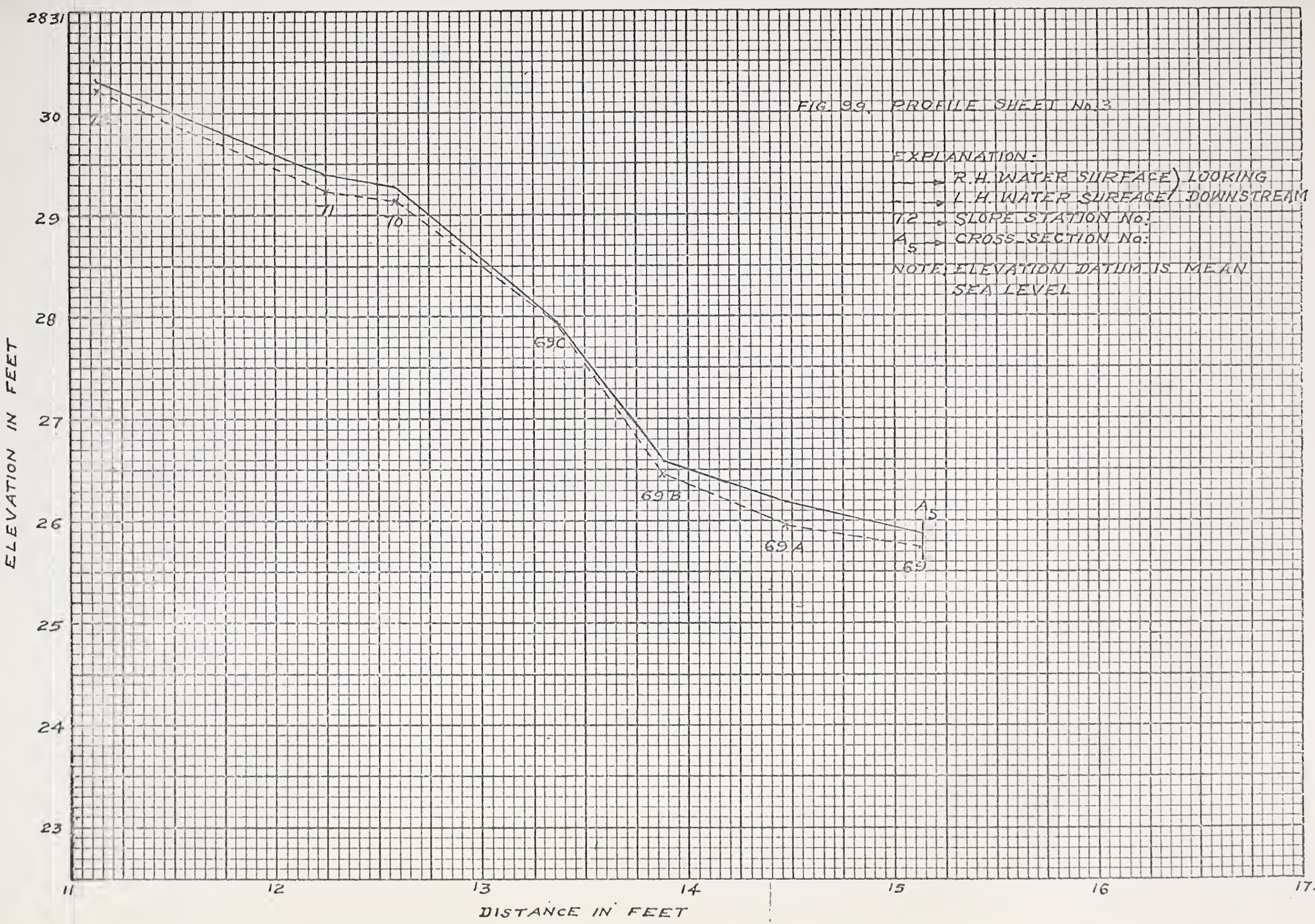
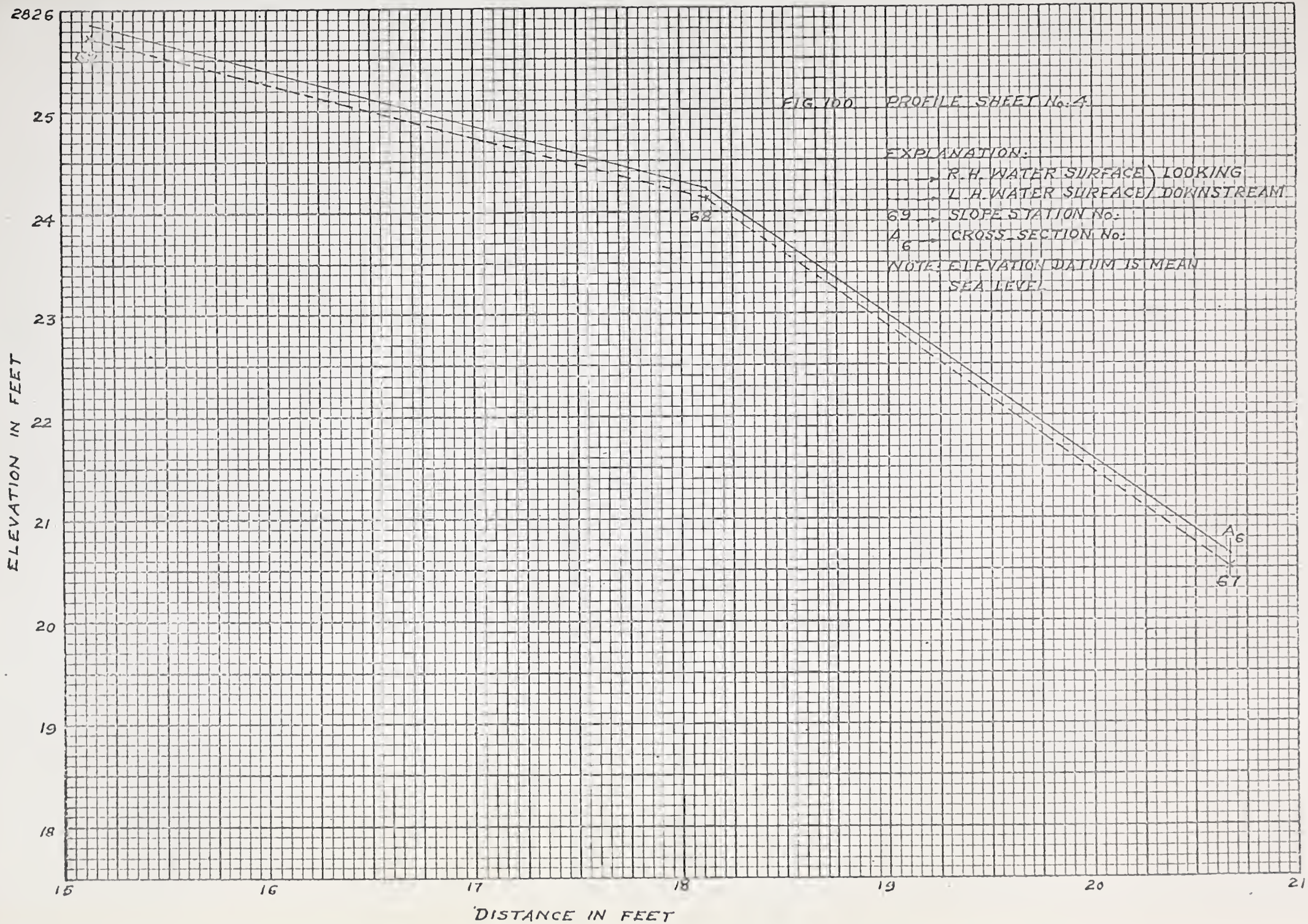


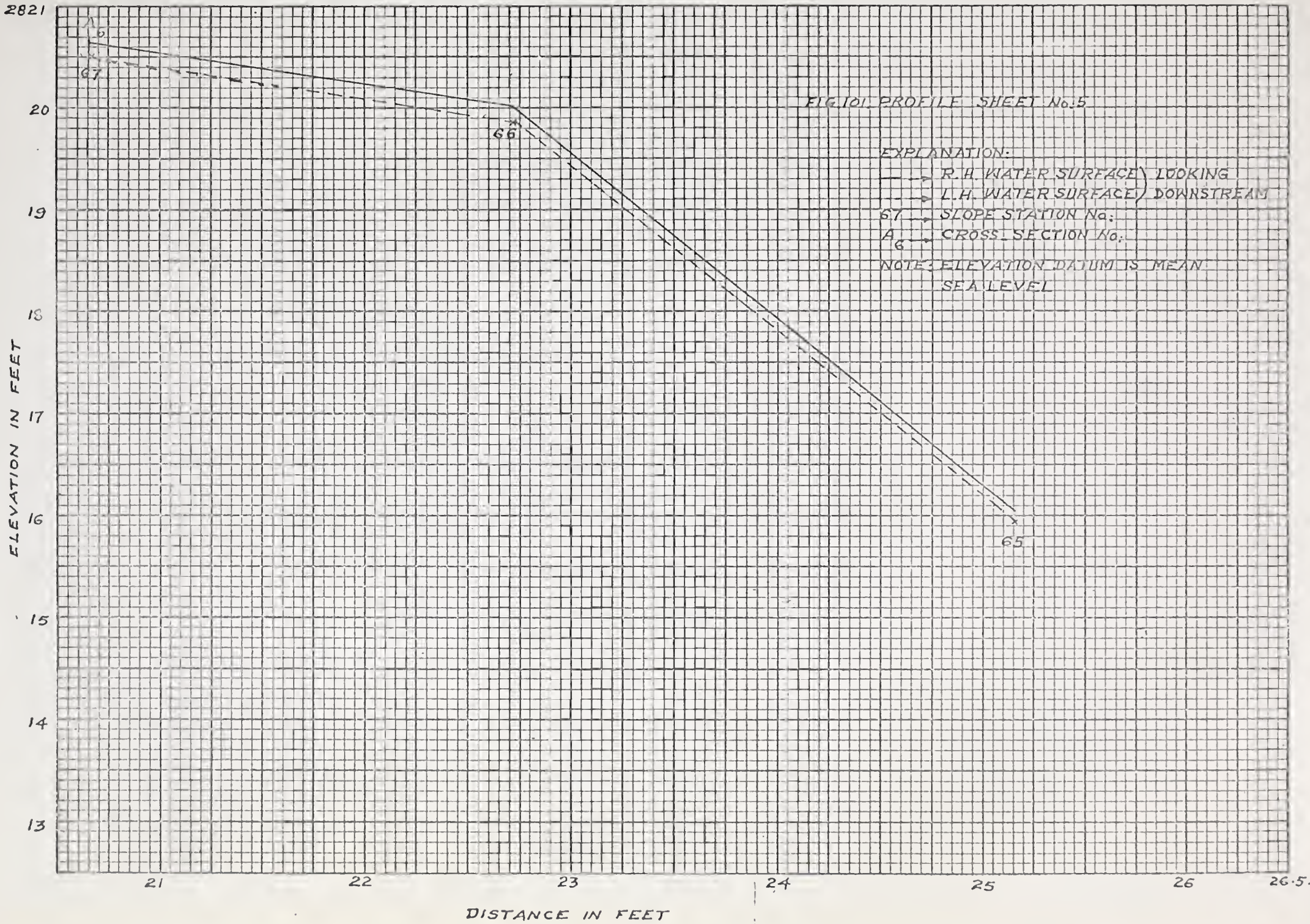
FIG 96. RED DEER RIVER AT RED DEER
MEAN DAILY DISCHARGE HYDROGRAPH
FOR THE MONTH OF SEPTEMBER 1961.

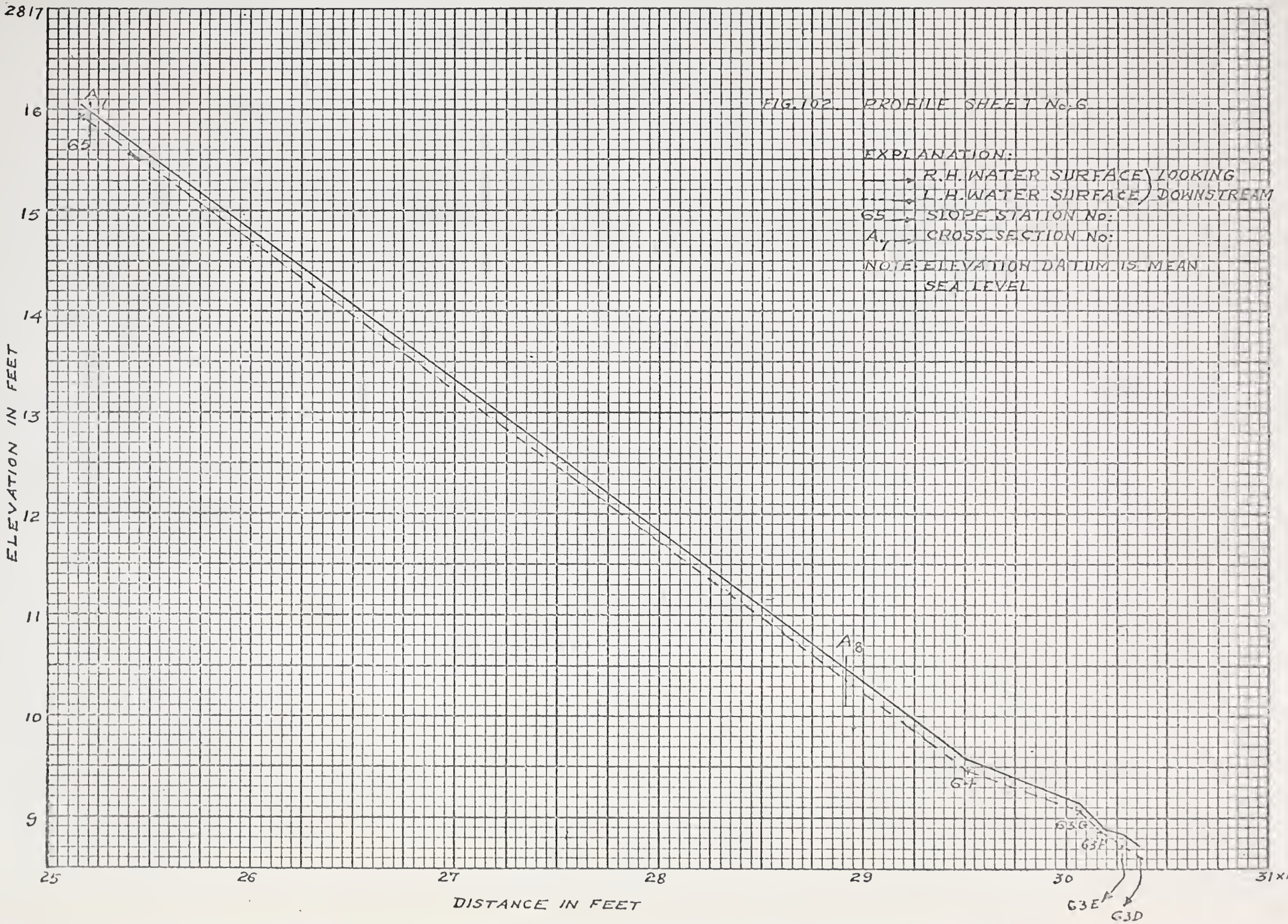

FIG. 97. PROFILE
EXPLANATION:
R.H. WATER SURFACE
L.H. WATER SURFACE
LOOKING DOWNSTREAM
82 → SLOPE STATION
A1 → CROSS SECTION No.
NOTE: ELEVATION DATUM IS MEAN
ELEVATION IN FEET
DISTANCE IN FEET
2840
39
38
37
36
35
34
33
32
5
10
15
20
25
30
35
40
45
50
55
60×100
A1
A2
A3
83
82
81
80
79
78
77

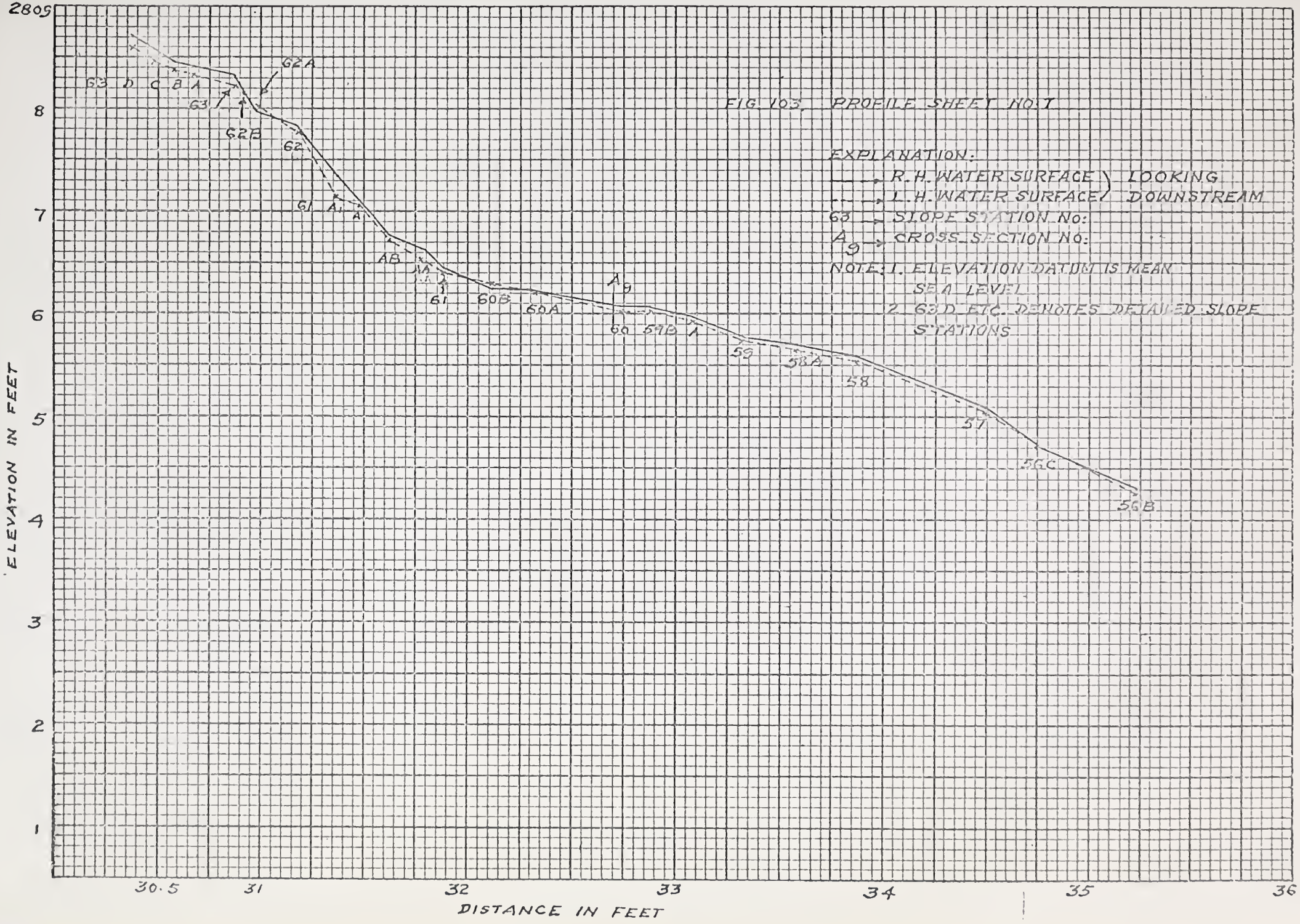

FIG 98. PROFILE SHEET No. 2
EXPLANATION:
R.H WATER SURFACE) LOOKING
L.H WATER SURFACE) DOWNSTREAM
77 → SLOPE STATION No.
A4 → CROSS-SECTION No.
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
ELEVATION IN FEET
2835
34
33
32
31
30
29
28
27
55
60
65
70
75
80
85
90
95
100
105
110
115 x100
DISTANCE IN FEET
77
76
75
74
73
72
A4

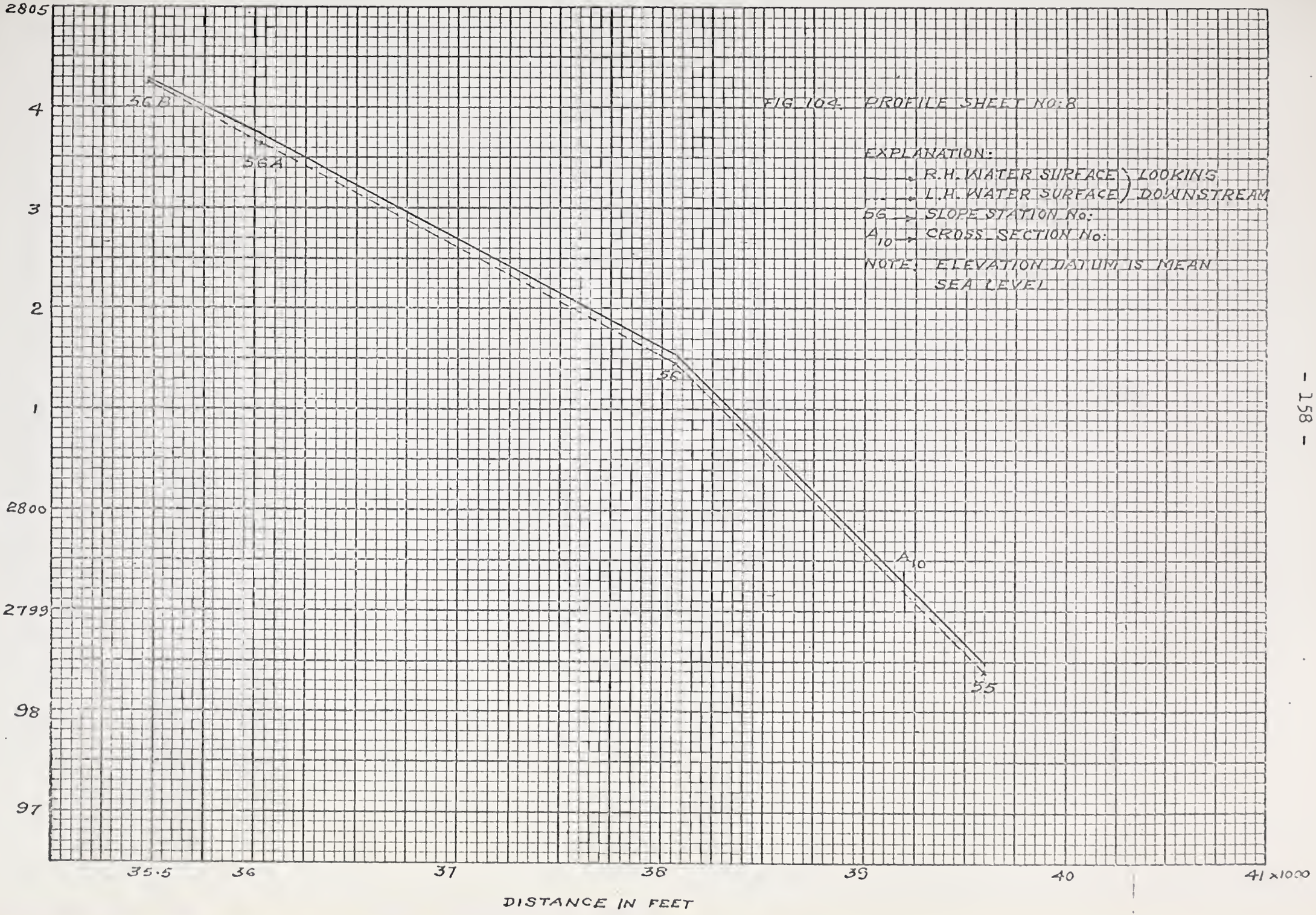

FIG 99. PROFILE SHEET No. 3
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
T.2 → SLOPE STATION No.
A5 → CROSS SECTION No.
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
ELEVATION IN FEET
DISTANCE IN FEET
2831
30
29
28
27
26
25
24
23
11
12
13
14
15
16
17 x 1000
11
10
69C
69B
69A
69
A5


2826
25
24
23
22
21
20
19
18
ELEVATION IN FEET
15
16
17
18
19
20
21 x 1000
DISTANCE IN FEET
FIG 100 PROFILE SHEET No. 4
EXPLANATION:
R.H. WATER SURFACE \ LOOKING
L.H. WATER SURFACE / DOWNSTREAM
69 → SLOPE STATION No:
A6 → CROSS SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
68
A6
67


FIG 101 PROFILE SHEET No.5
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
67 → SLOPE STATION No.
A6 → CROSS SECTION No.
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
67
66
65
2821
20
19
18
17
16
15
14
13
ELEVATION IN FEET
21
22
23
24
25
26
26·5×1000
DISTANCE IN FEET


FIG. 102. PROFILE SHEET No. 6
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
65 SLOPE STATION No:
A7 CROSS-SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
A7
65
A8
G-1
G3G
G3F
G3E
G3D
2817
16
15
14
13
12
11
10
9
ELEVATION IN FEET
25
26
27
28
29
30
31×1000
DISTANCE IN FEET


2805
8
7
6
5
4
3
2
1
ELEVATION IN FEET
63 D C B A
63
62A
62B
62
61 A
A
AB
1A
A
61
60B
60A
A9
60 59B A
59
58A
58
57
56C
56B
30.5
31
32
33
34
35
36×1000
DISTANCE IN FEET
FIG. 103 PROFILE SHEET NO: I
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
63 → SLOPE STATION No:
A9 → CROSS-SECTION No:
NOTE: 1. ELEVATION DATUM IS MEAN SEA LEVEL
2. 63 D ETC. DENOTES DETAILED SLOPE STATIONS


FIG 104. PROFILE SHEET NO: 8
EXPLANATION:
R.H. WATER SURFACE } LOOKING
L.H. WATER SURFACE } DOWNSTREAM
SG → SLOPE STATION No:
A10 → CROSS SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
2805
4
3
2
1
2800
2799
98
97
ELEVATION IN FEET
56 B
56 A
56
A10
55
35·5
36
37
38
39
40
41 x1000
DISTANCE IN FEET

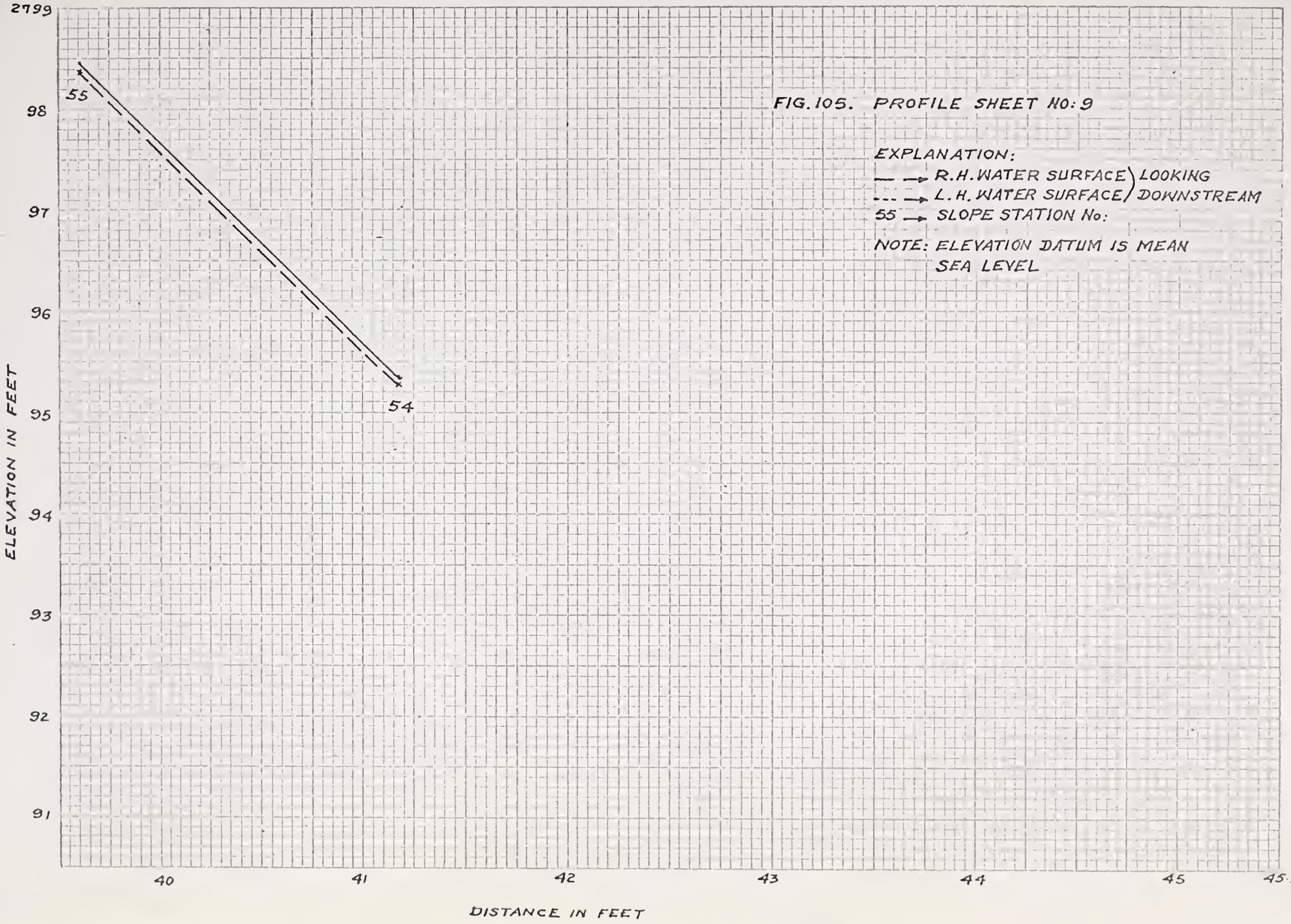
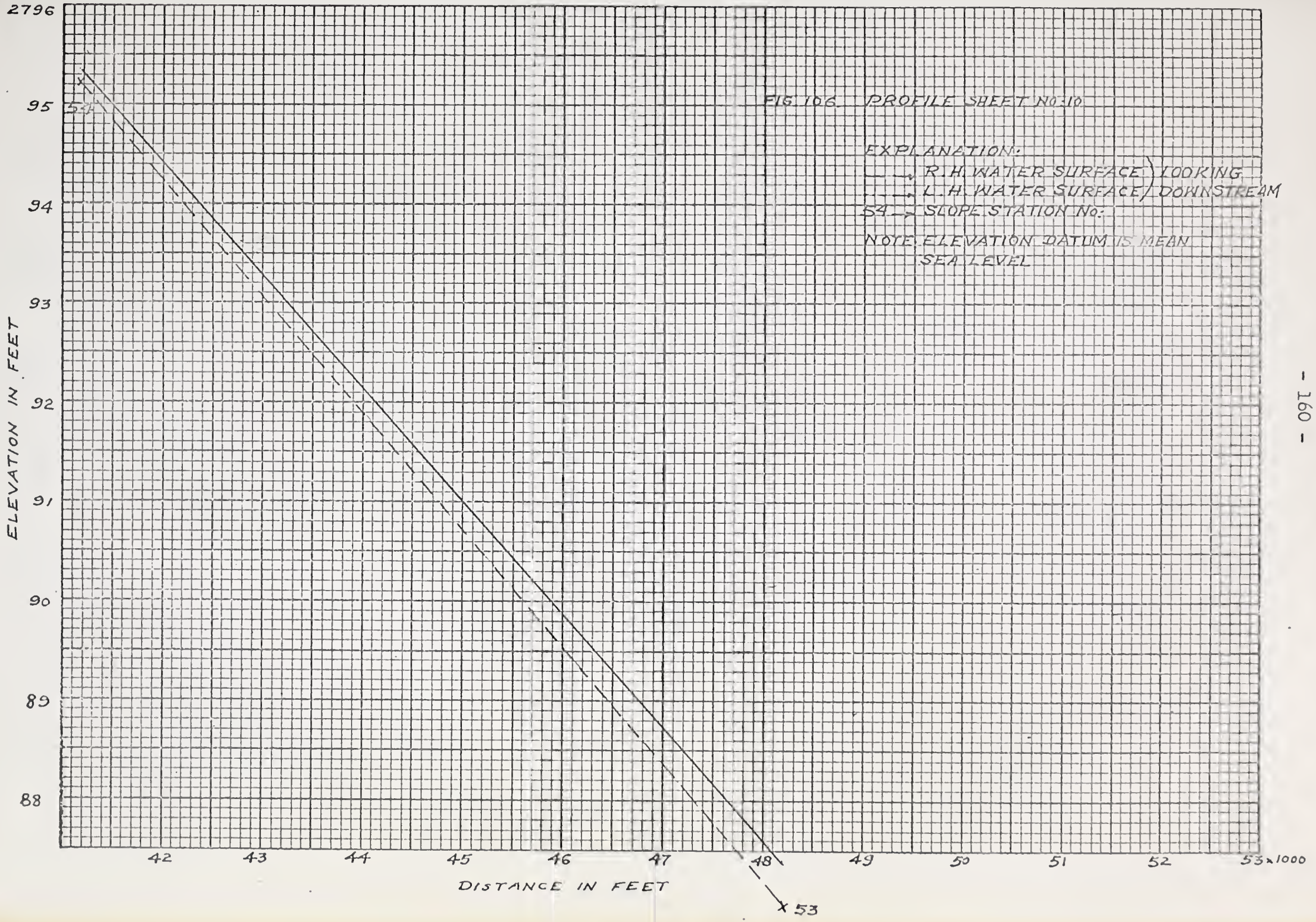


FIG. 105. PROFILE SHEET NO: 9

EXPLANATION:

— → R.H. WATER SURFACE) LOOKING
--- → L.H. WATER SURFACE) DOWNSTREAM
55 → SLOPE STATION No:

NOTE: ELEVATION DATUM IS MEAN SEA LEVEL


2796
95
94
93
92
91
90
89
88
ELEVATION IN FEET
54
42
43
44
45
46
47
48
49
50
51
52
53×1000
DISTANCE IN FEET
53
FIG. 106. PROFILE SHEET NO. 10
EXPLANATION:
R.H. WATER SURFACE } LOOKING
L.H. WATER SURFACE } DOWNSTREAM
54 → SLOPE STATION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

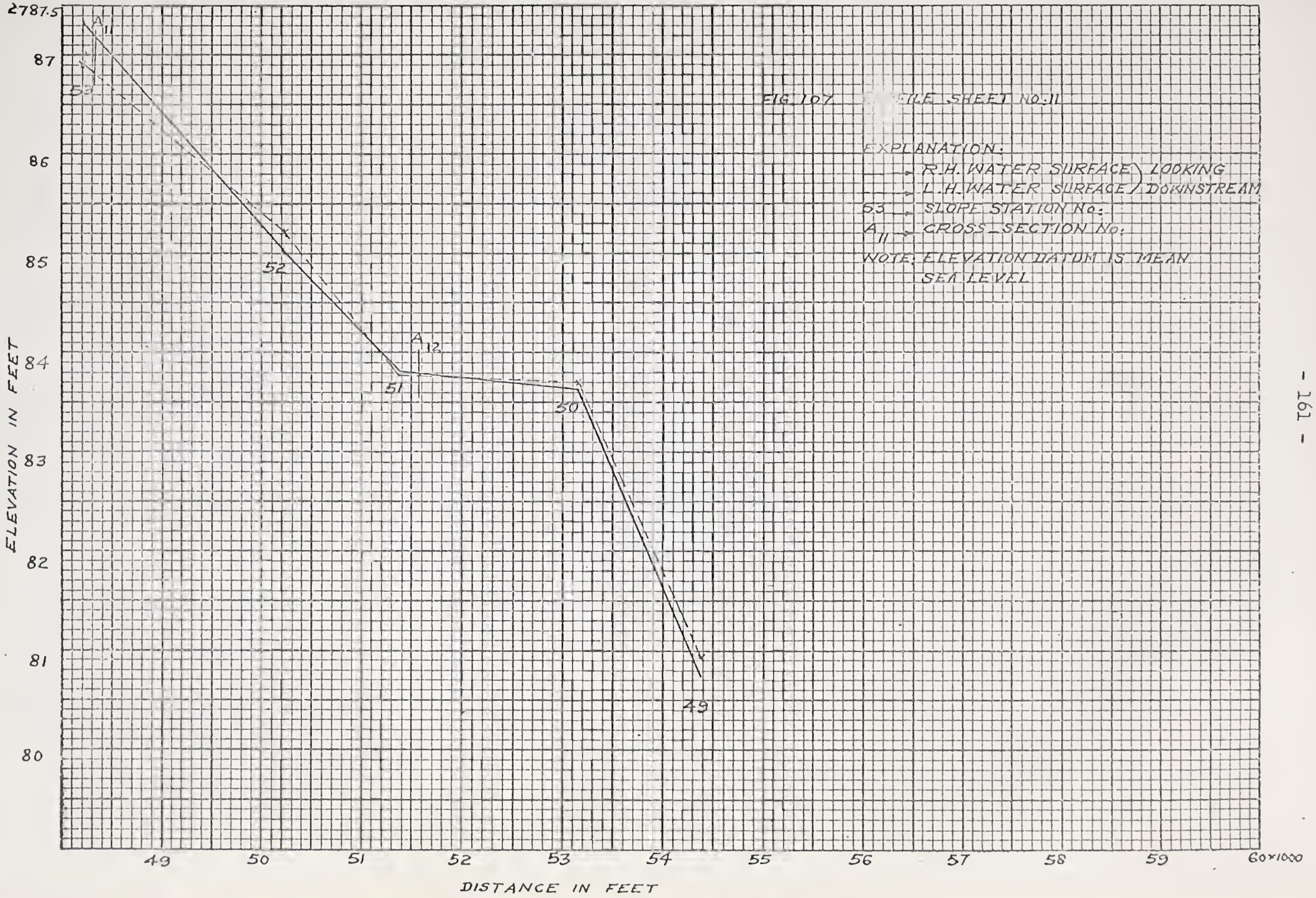


FIG. 107 [illegible] SHEET NO: 11

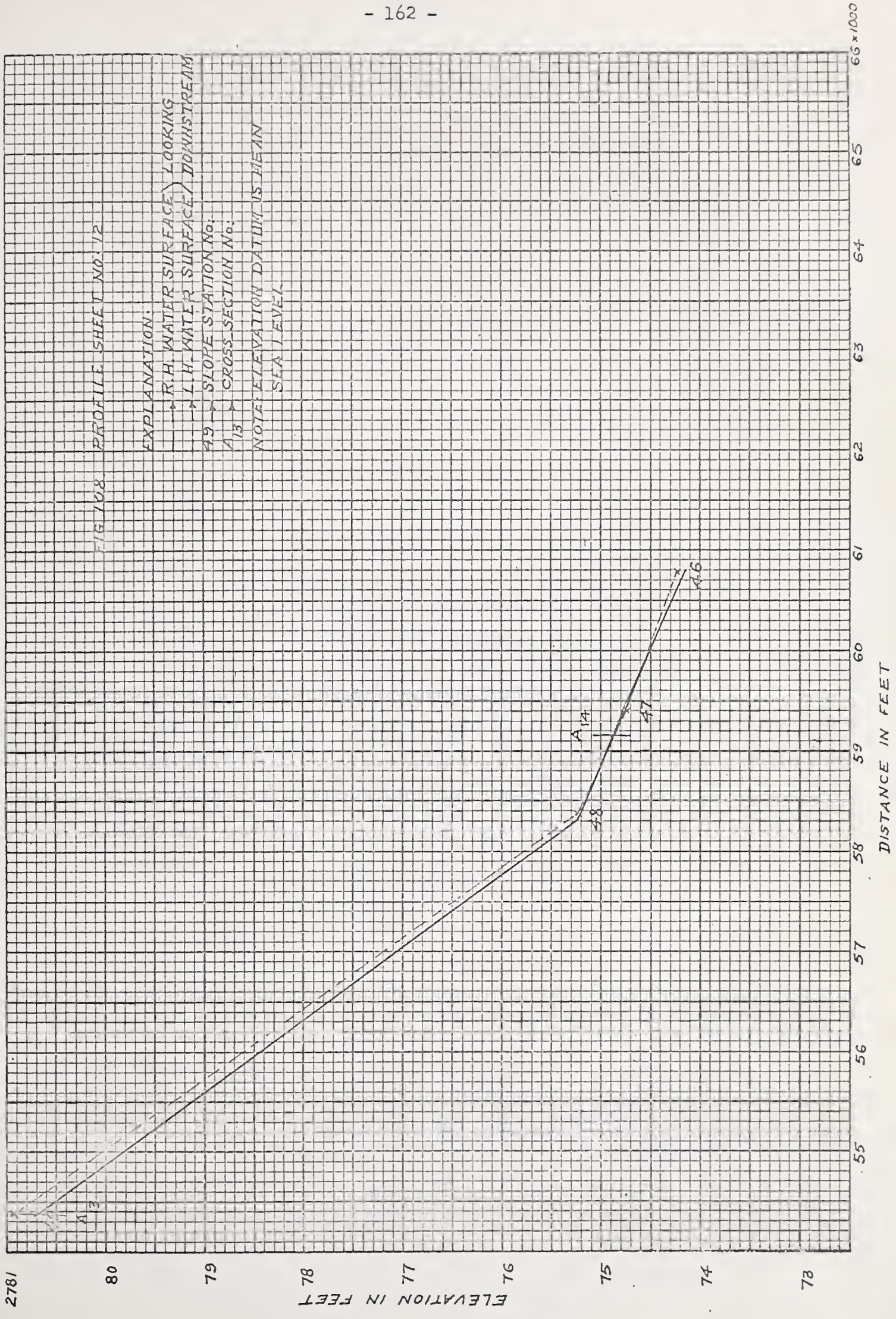
EXPLANATION:

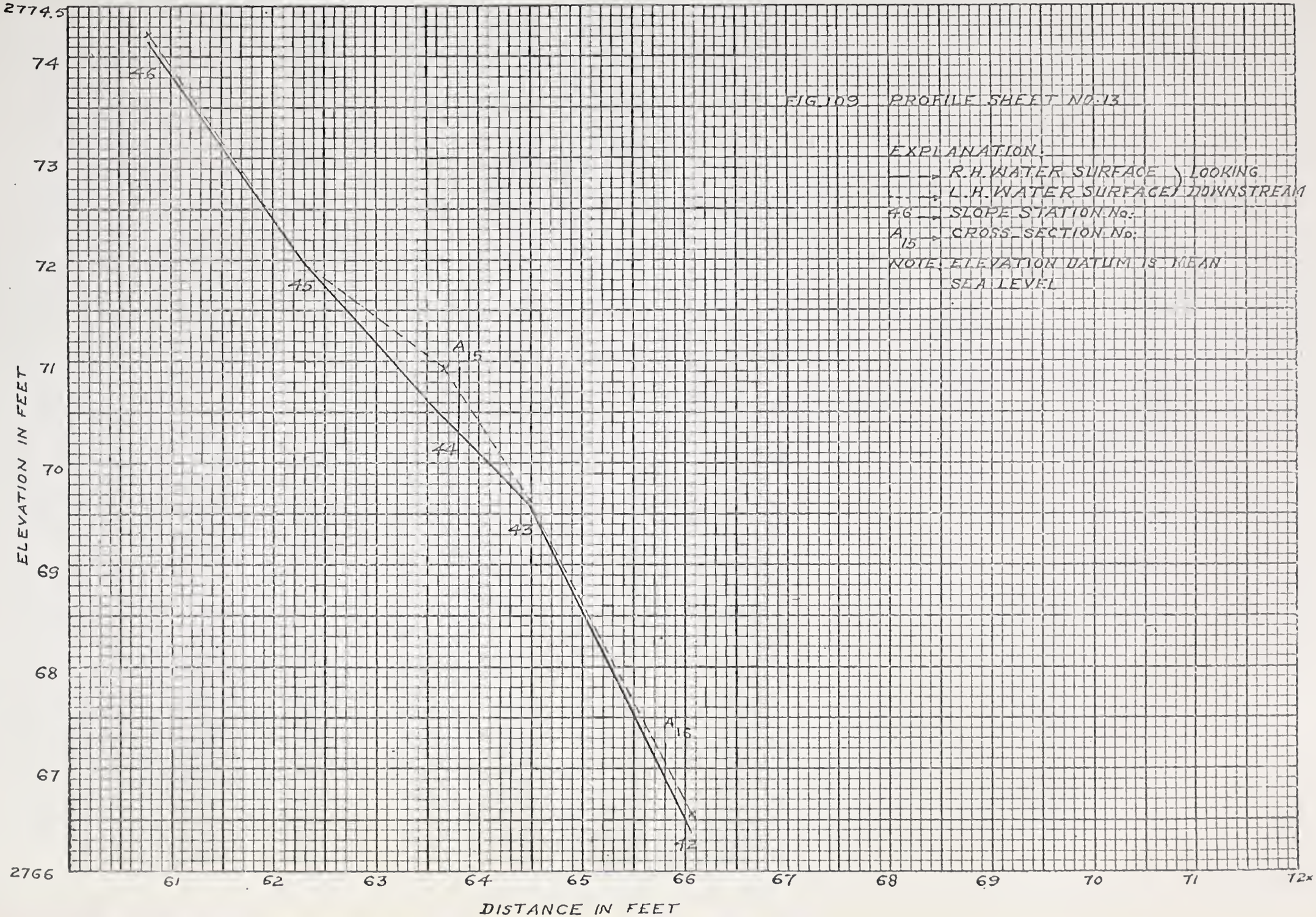
→ R.H. WATER SURFACE } LOOKING
→ L.H. WATER SURFACE } DOWNSTREAM

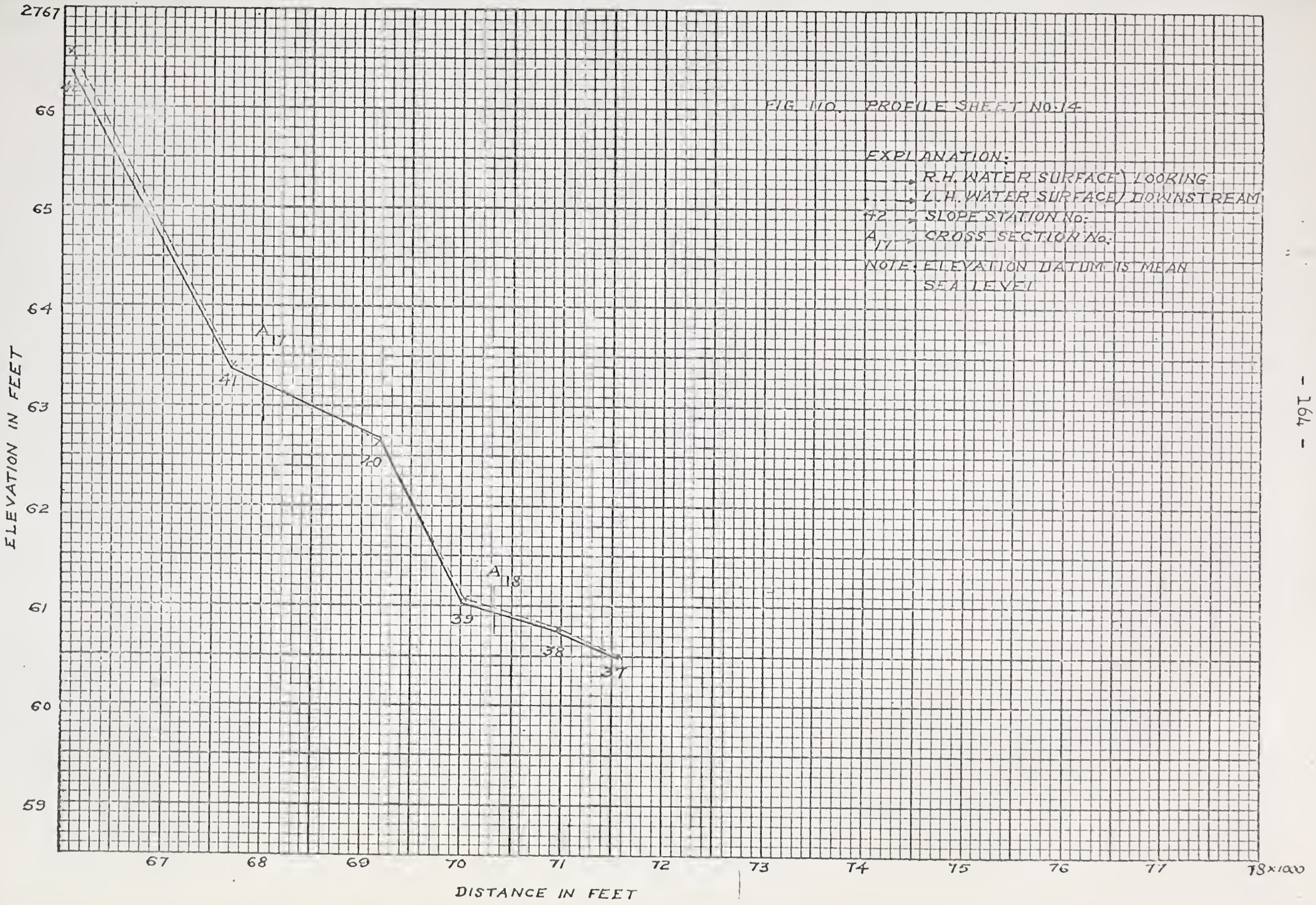
53 → SLOPE STATION No:

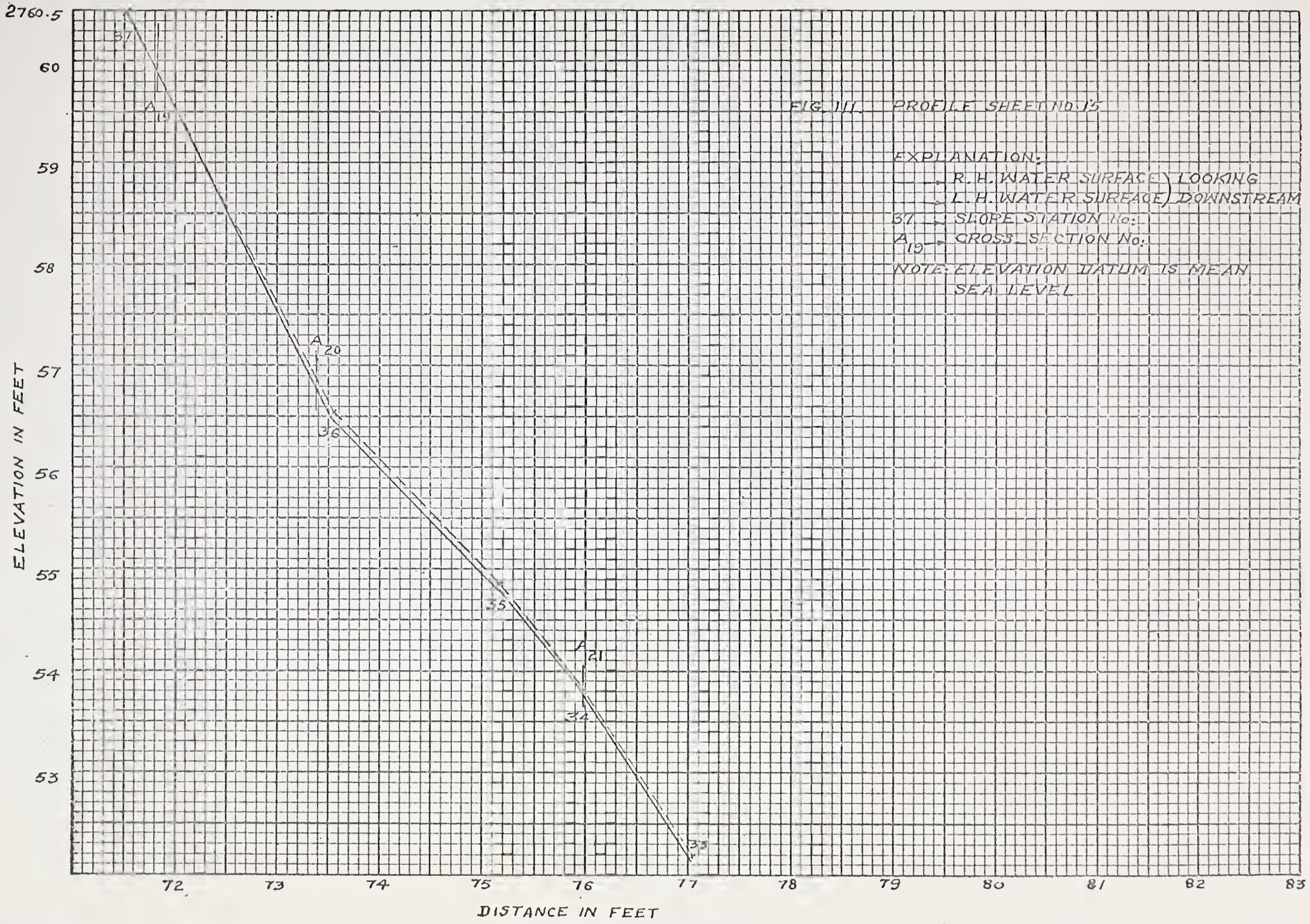
A_{11} → CROSS-SECTION No:

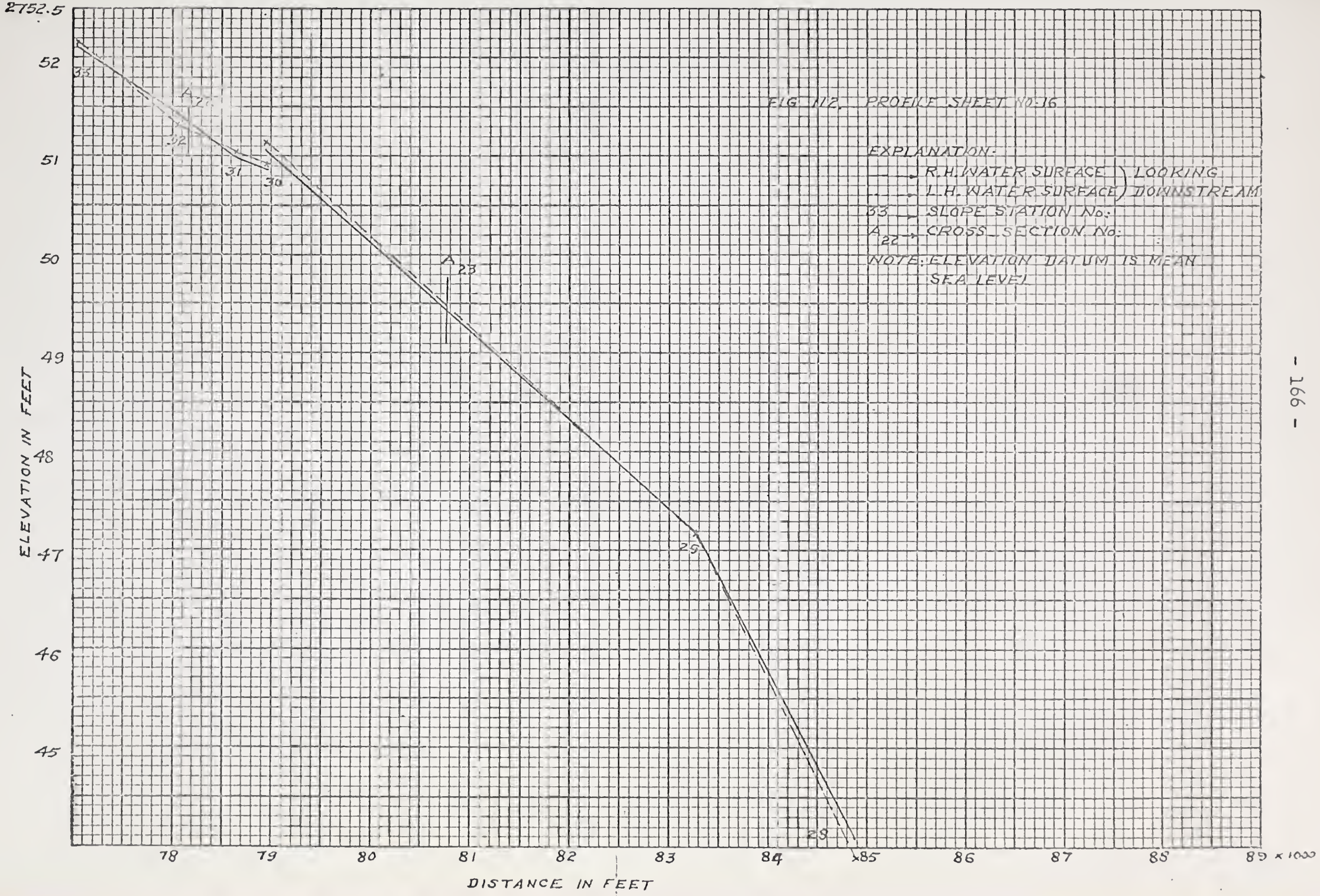
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL


FIG 108 PROFILE SHEET NO. 12
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
49 → SLOPE STATION No:
A13 → CROSS SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
A13
A14
48
47
46
2781
80
79
78
77
76
75
74
73
55
56
57
58
59
60
61
62
63
64
65
66 x 1000
ELEVATION IN FEET
DISTANCE IN FEET


2774.5
74
73
72
71
70
69
68
67
2766
ELEVATION IN FEET
46
45
44
43
42
A15
A16
61
62
63
64
65
66
67
68
69
70
71
72×1000
DISTANCE IN FEET
FIG 109 PROFILE SHEET NO: 13
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
46 → SLOPE STATION No:
A15 → CROSS SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL


FIG. NO. PROFILE SHEET NO. 14
EXPLANATION:
R.H. WATER SURFACE } LOOKING
L.H. WATER SURFACE } DOWNSTREAM
#2 → SLOPE STATION No:
A17 → CROSS SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
ELEVATION IN FEET
DISTANCE IN FEET
2767
66
65
64
63
62
61
60
59
67
68
69
70
71
72
73
74
75
76
77
78x100
A17
A18
41
40
39
38
37


2760.5
60
59
58
57
56
55
54
53
ELEVATION IN FEET
72
73
74
75
76
77
78
79
80
81
82
83
DISTANCE IN FEET
37
A 19
A 20
36
35
A 21
34
33
FIG. III. PROFILE SHEET No. 15
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
37 → SLOPE STATION No:
A 19 → CROSS SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL


2752.5
52
51
50
49
48
47
46
45
ELEVATION IN FEET
33
32
31
30
29
28
A22
A23
78
79
80
81
82
83
84
85
86
87
88
89 x 1000
DISTANCE IN FEET
FIG NO. PROFILE SHEET NO. 16
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
33 — SLOPE STATION No.
A22 — CROSS SECTION No.
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL

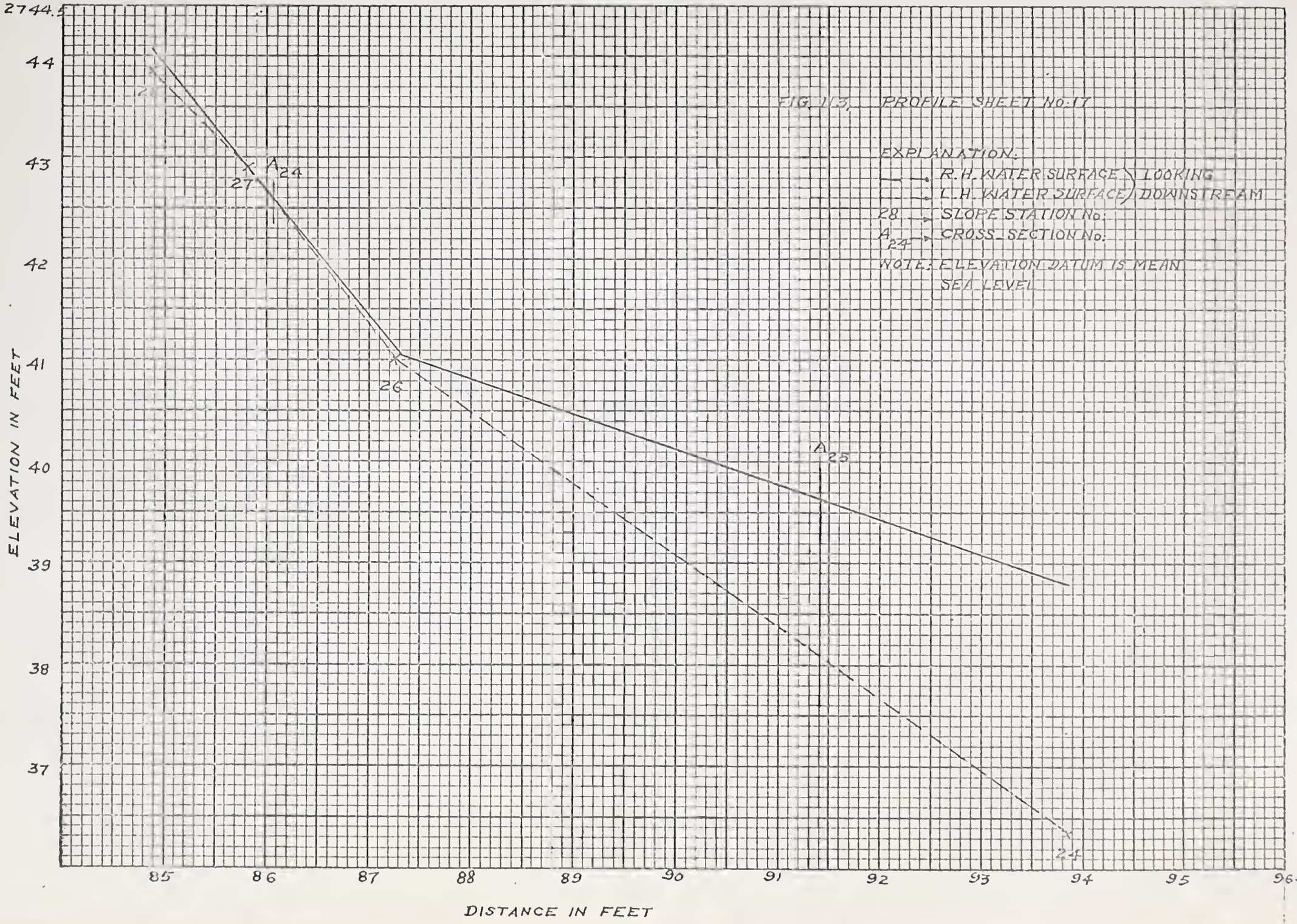


FIG. 113. PROFILE SHEET NO. 17

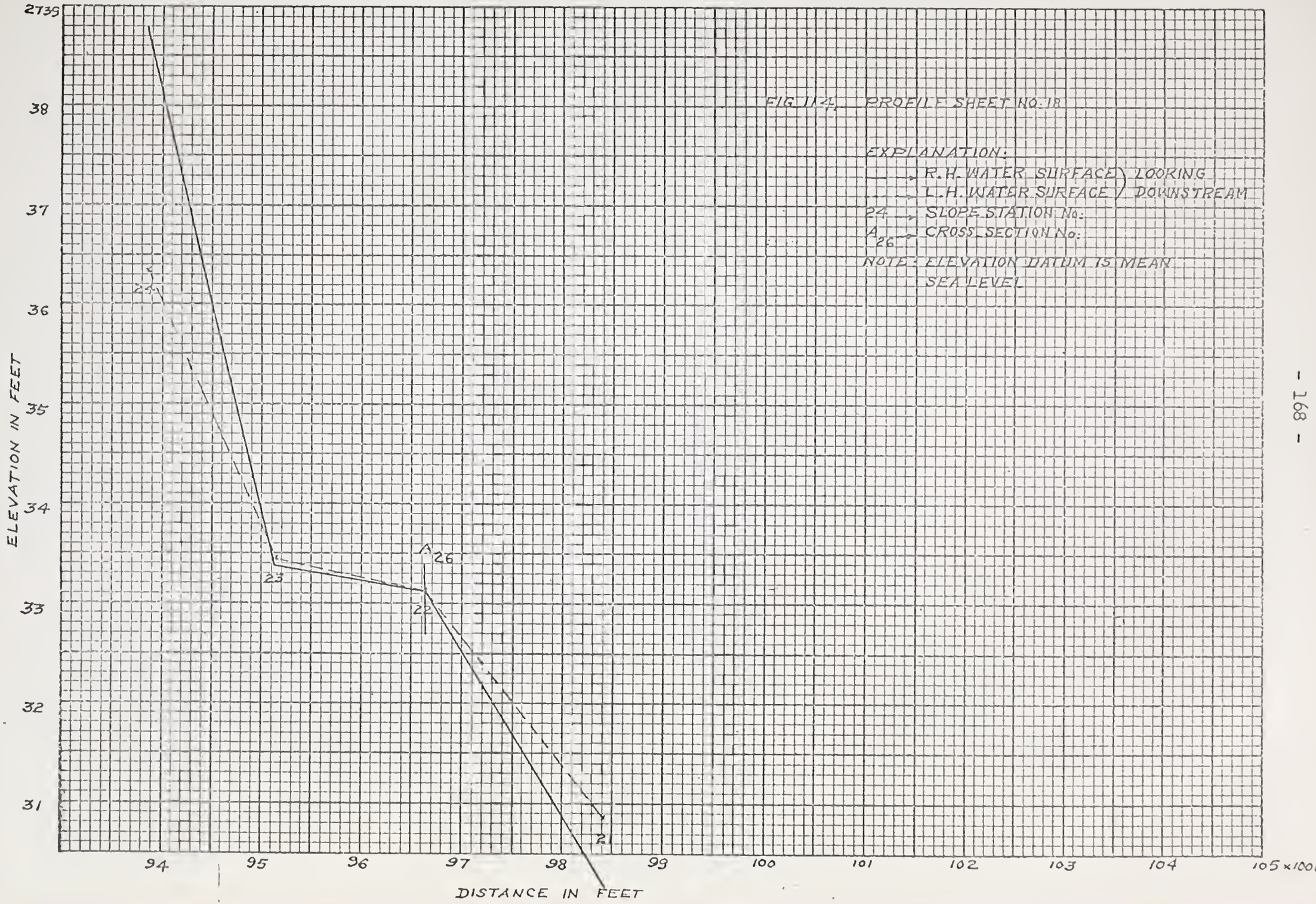
EXPLANATION:

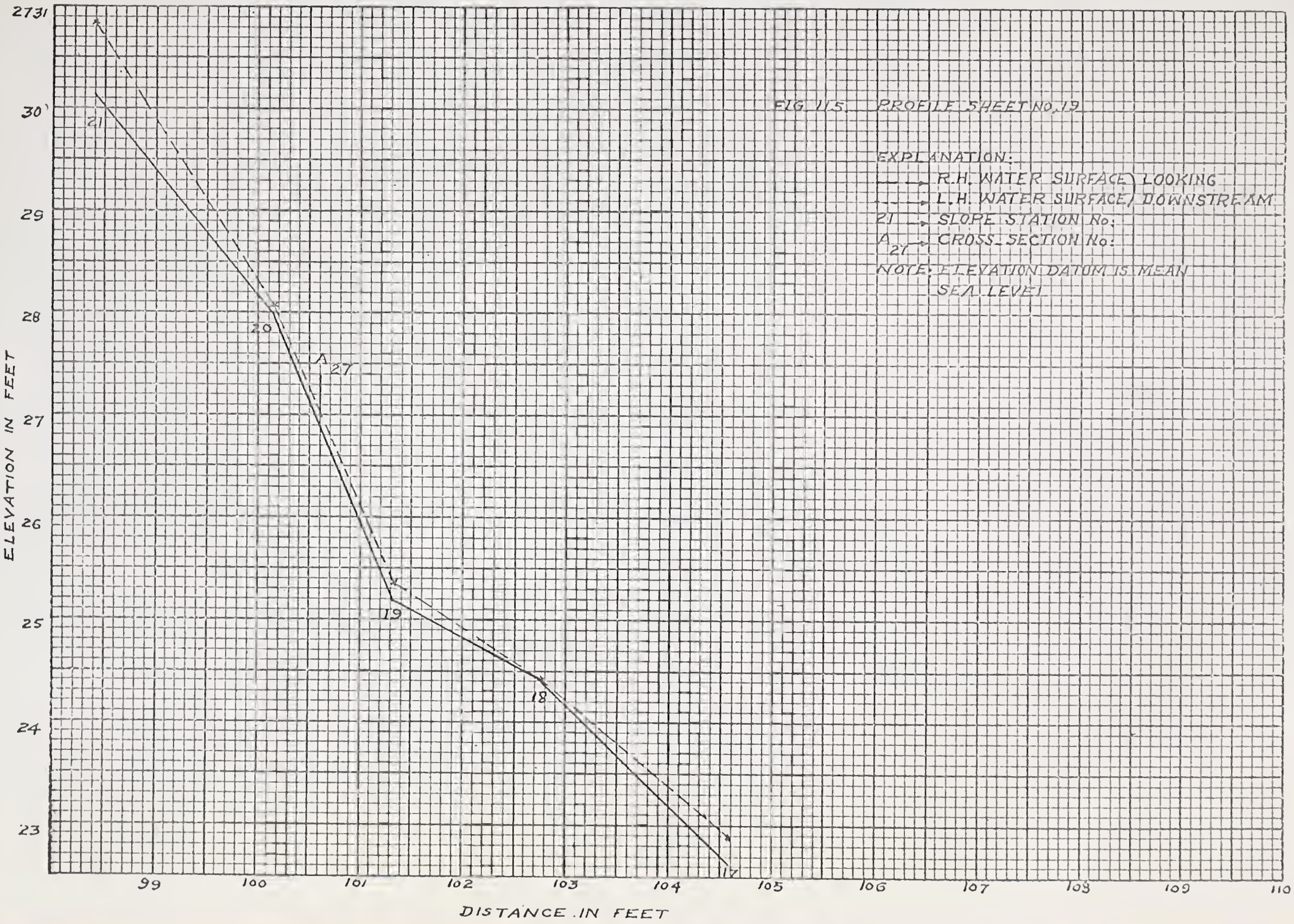
R.H. WATER SURFACE } LOOKING
L.H. WATER SURFACE } DOWNSTREAM

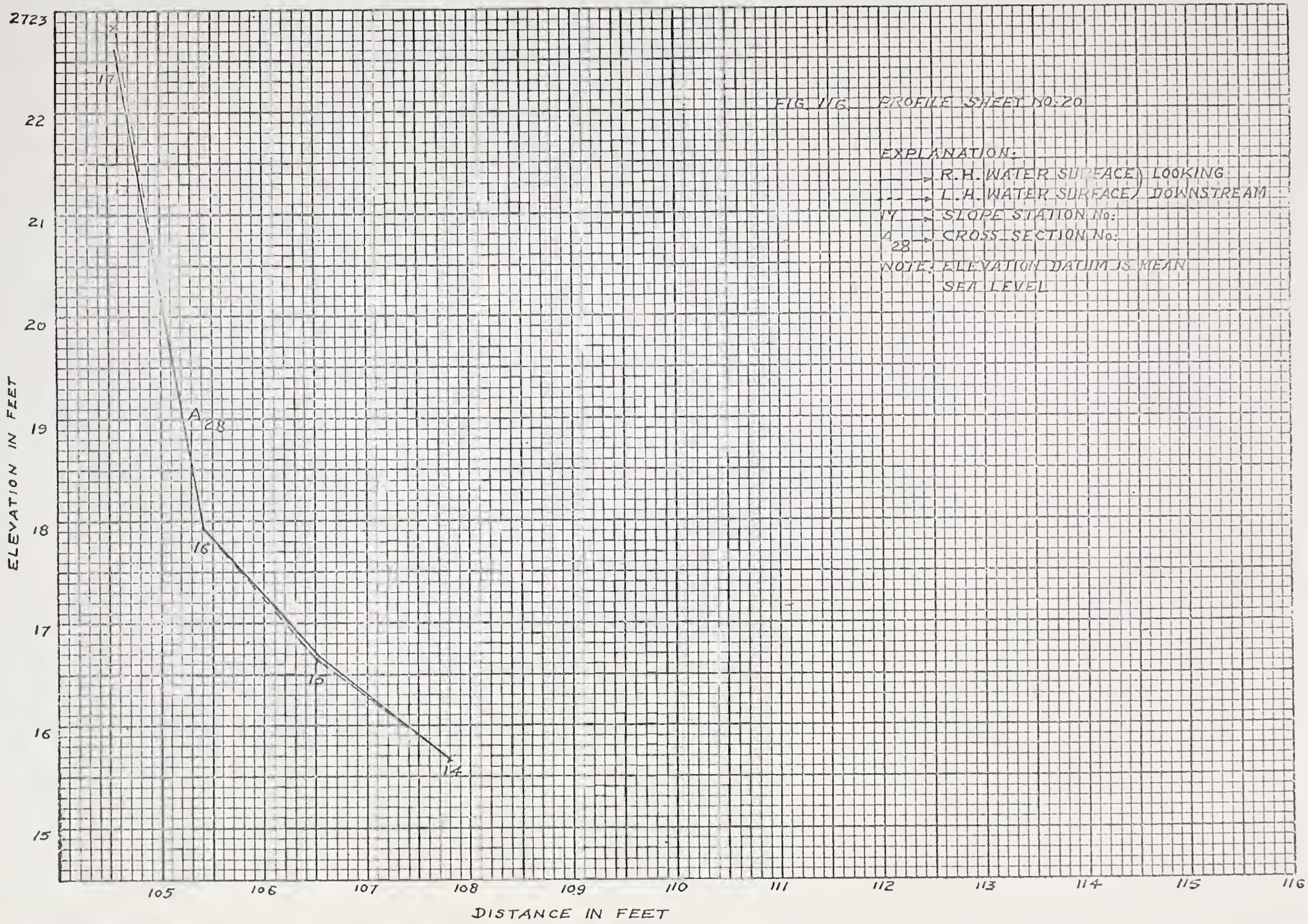
28 → SLOPE STATION No.

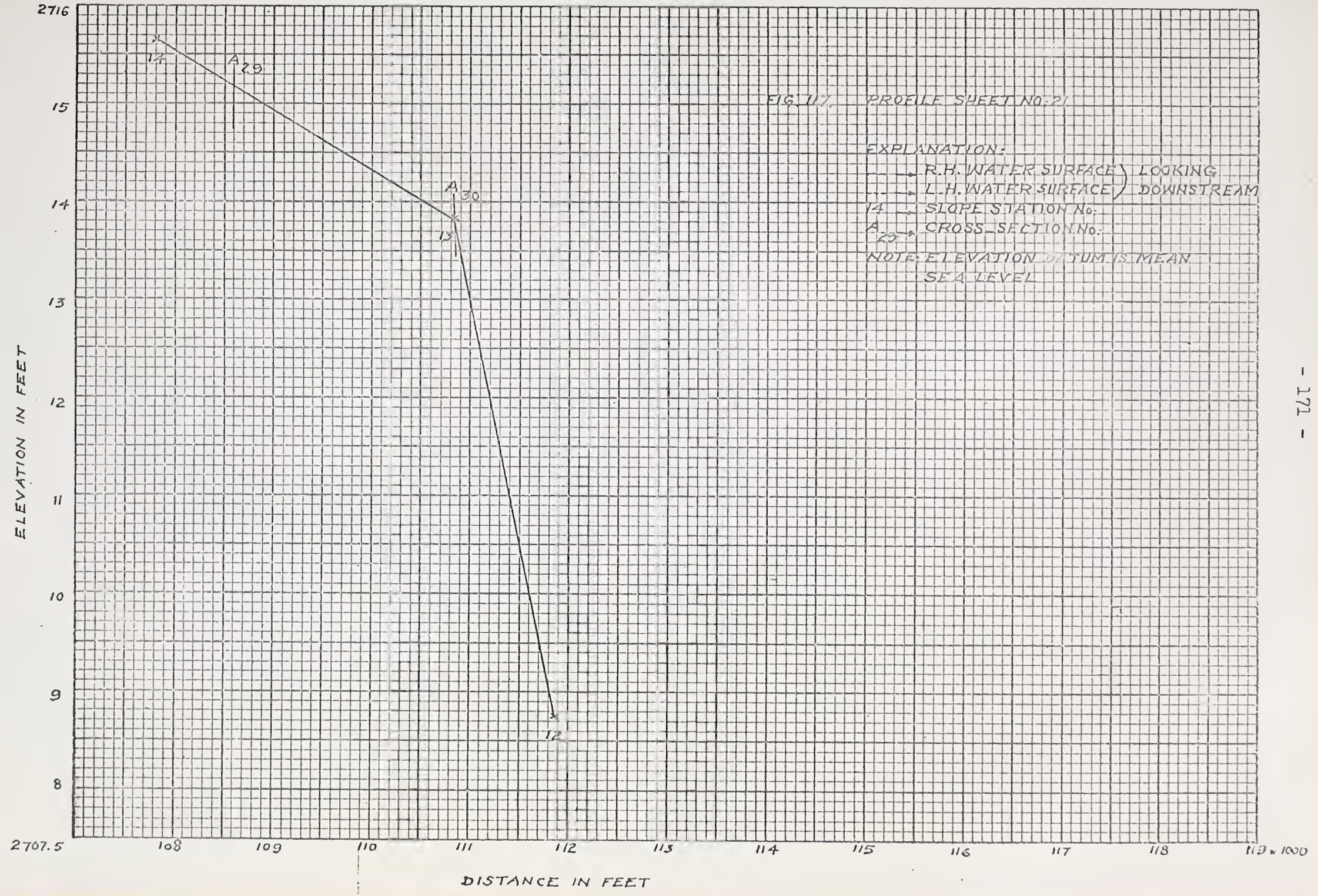
A_{24} → CROSS-SECTION No.

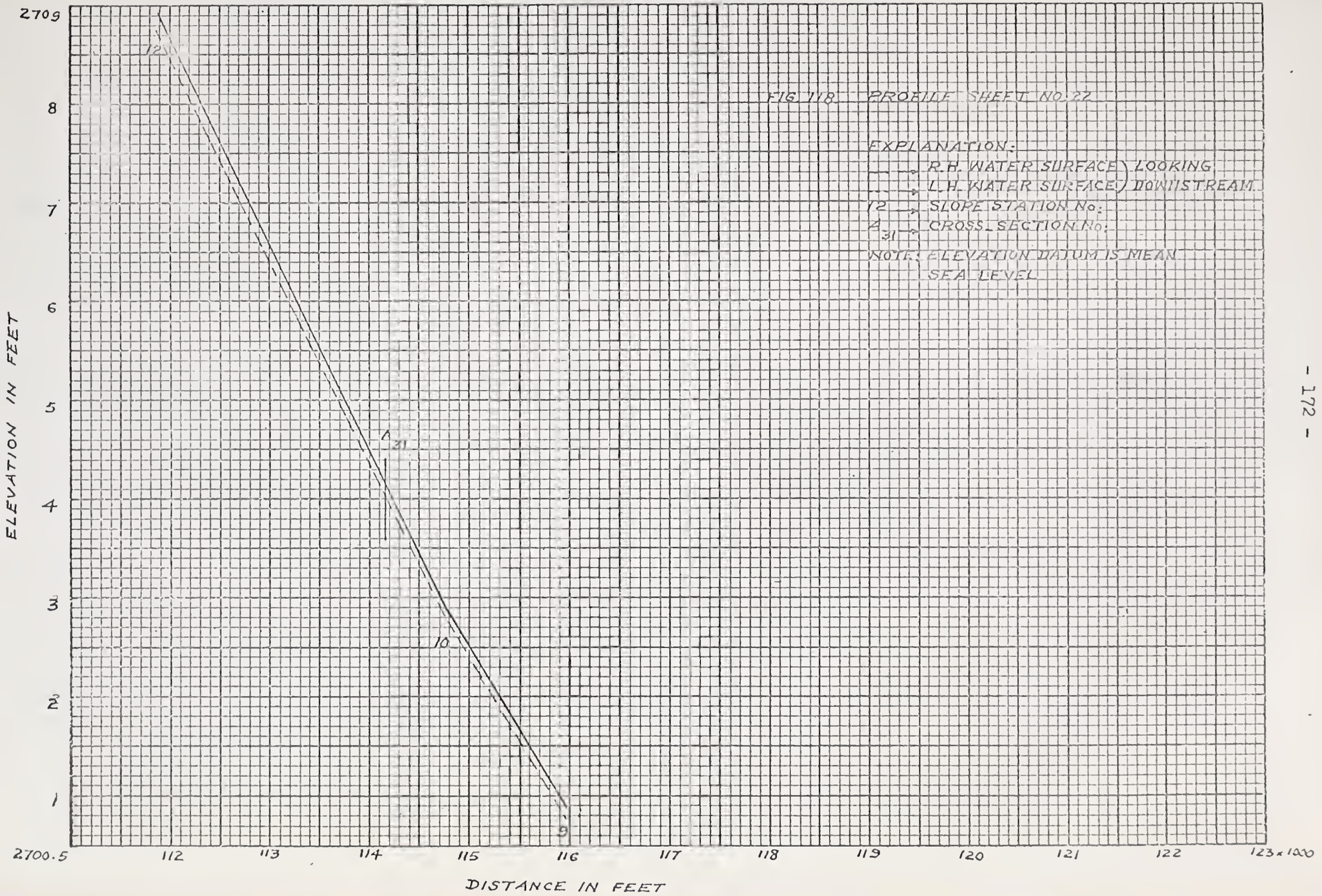
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL


FIG II-4 PROFILE SHEET NO. 18
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
24 → SLOPE STATION No:
A26 → CROSS SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
ELEVATION IN FEET
DISTANCE IN FEET
2739
38
37
36
35
34
33
32
31
94
95
96
97
98
99
100
101
102
103
104
105 x 1000
25
23
A26
22
21


FIG. 11.5. PROFILE SHEET NO. 19
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
21 → SLOPE STATION No:
A 27 → CROSS-SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
ELEVATION IN FEET
DISTANCE IN FEET
2731
30
29
28
27
26
25
24
23
99
100
101
102
103
104
105
106
107
108
109
110 x 1000
21
20
A 27
19
18
17


2723
22
21
20
19
18
17
16
15
ELEVATION IN FEET
17
A 28
16
15
14
105
106
107
108
109
110
111
112
113
114
115
116 x 1000
DISTANCE IN FEET
FIG 116 PROFILE SHEET NO: 20
EXPLANATION:
R.H. WATER SURFACE } LOOKING
L.H. WATER SURFACE } DOWNSTREAM
17 → SLOPE STATION No:
A 28 → CROSS SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL


2716
15
14
13
12
11
10
9
8
2707.5
ELEVATION IN FEET
14
A 29
A 30
13
12
108
109
110
111
112
113
114
115
116
117
118
119 x 1000
DISTANCE IN FEET
FIG. 117. PROFILE SHEET NO. 21.
EXPLANATION:
R.H. WATER SURFACE } LOOKING
L.H. WATER SURFACE } DOWNSTREAM
14 → SLOPE STATION No.
A 29 → CROSS SECTION No.
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL


FIG 118 PROFILE SHEET NO. 22
EXPLANATION:
R.H. WATER SURFACE) LOOKING
L.H. WATER SURFACE) DOWNSTREAM
12 → SLOPE STATION No:
A31 → CROSS-SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
ELEVATION IN FEET
2709
8
7
6
5
4
3
2
1
2700.5
112
113
114
115
116
117
118
119
120
121
122
123 x 1000
DISTANCE IN FEET
12
A31
10
9

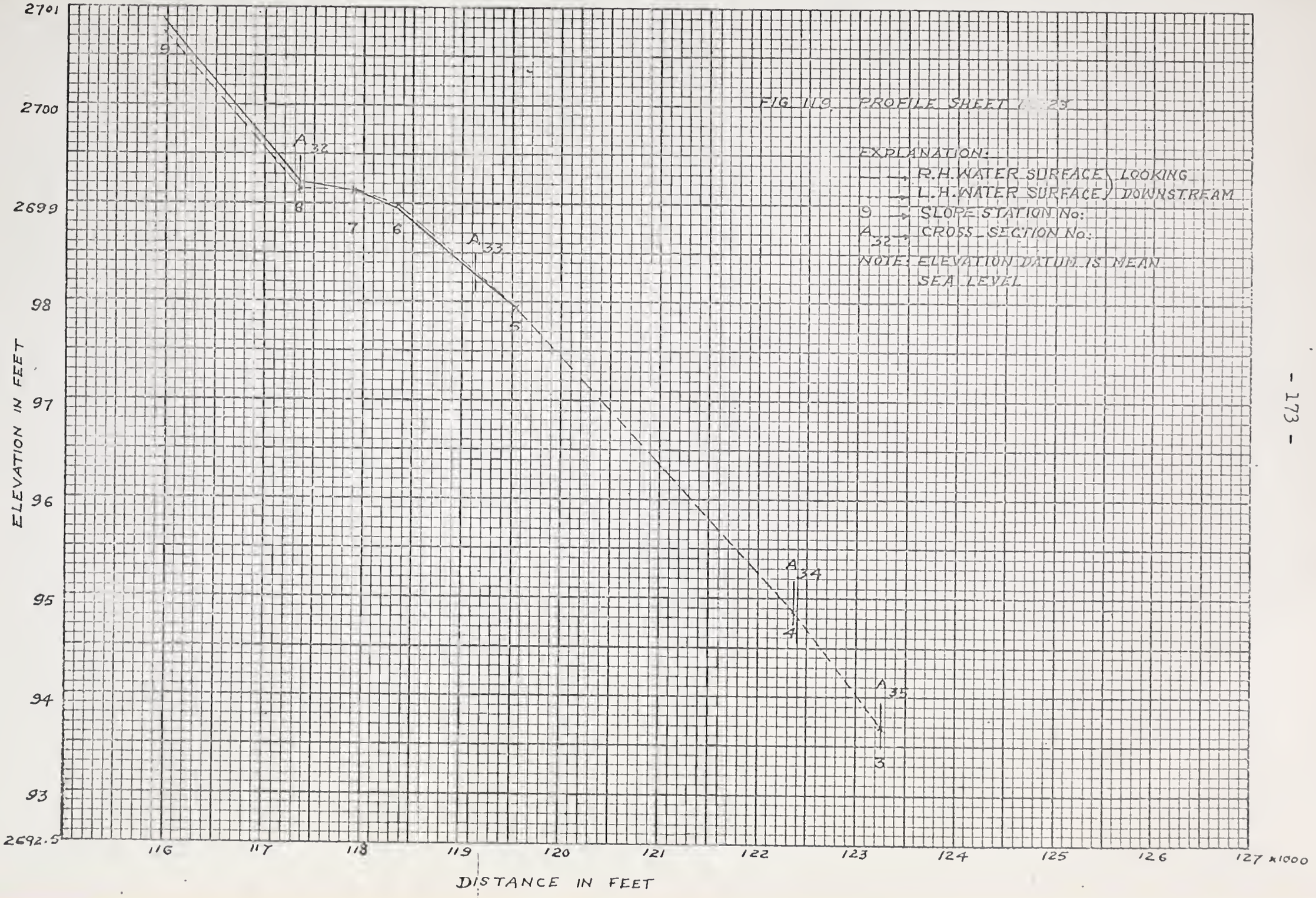
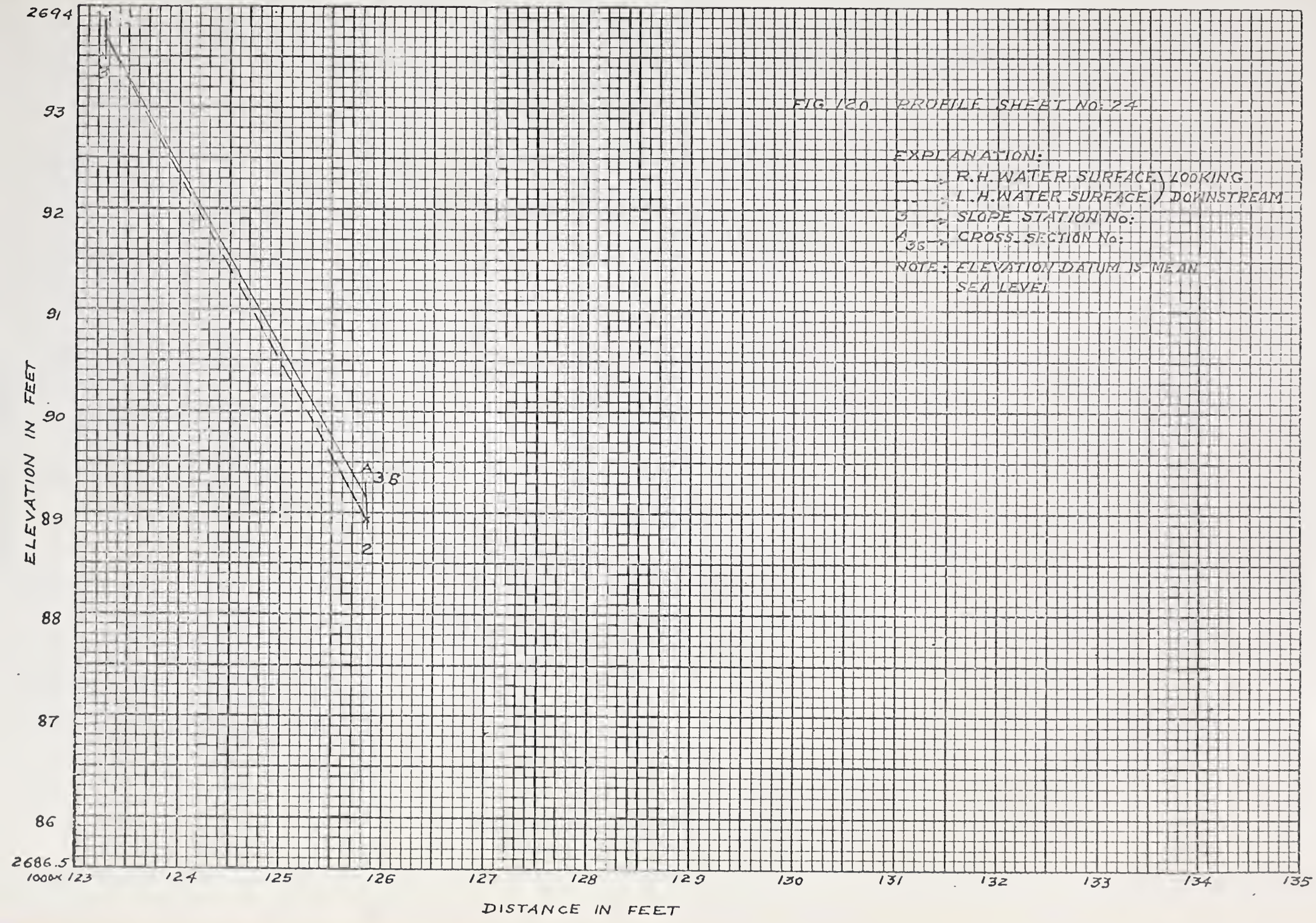
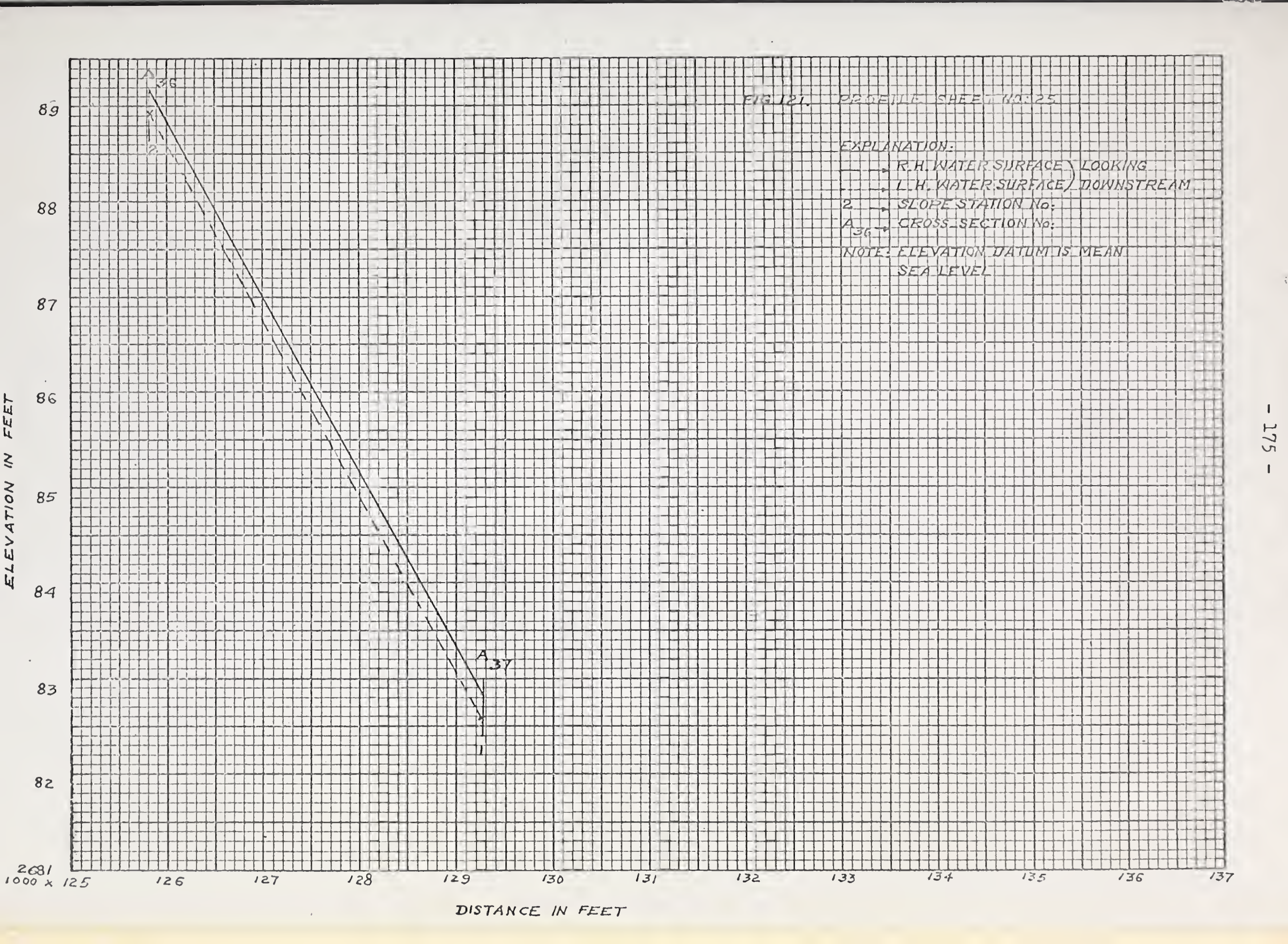
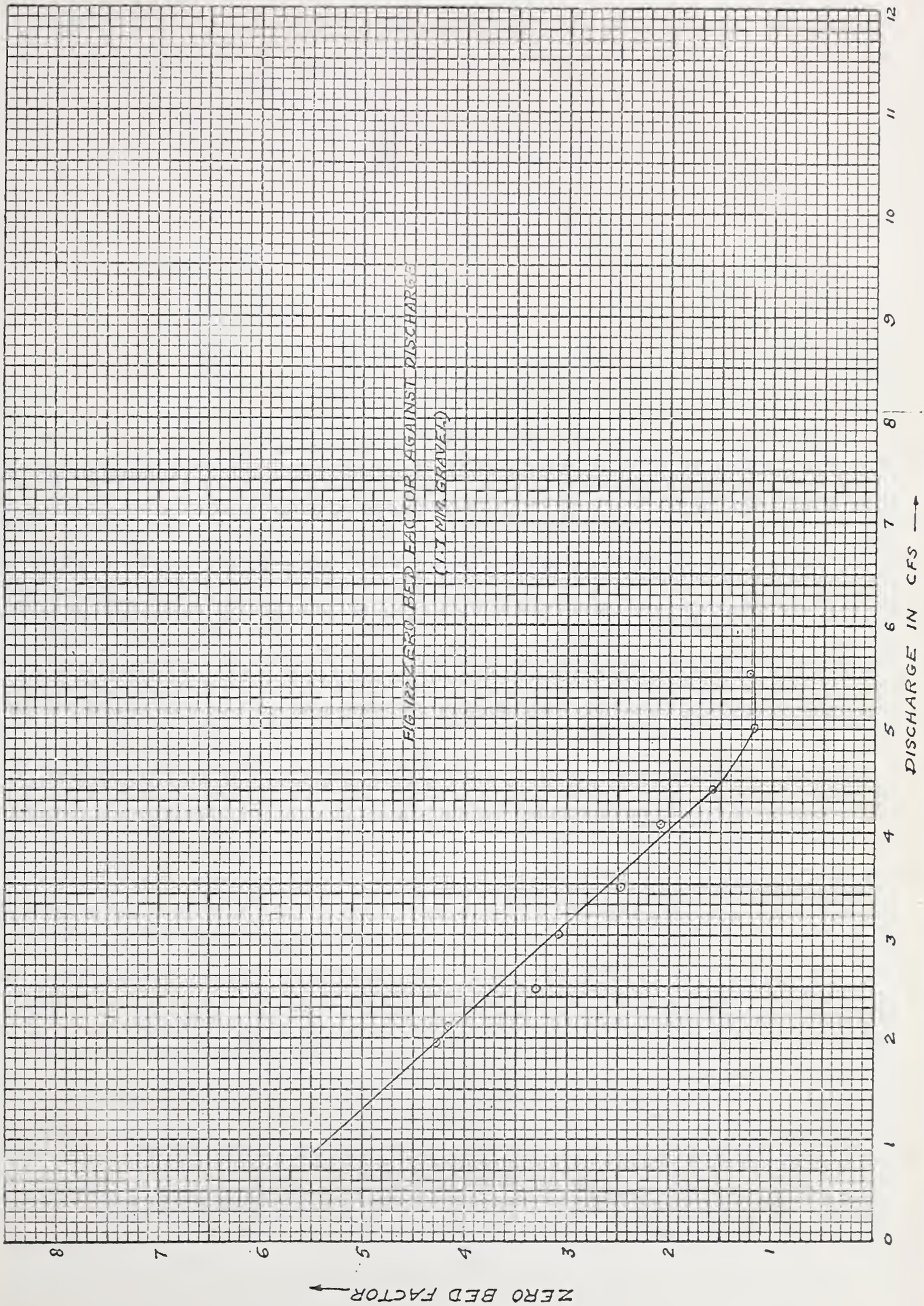
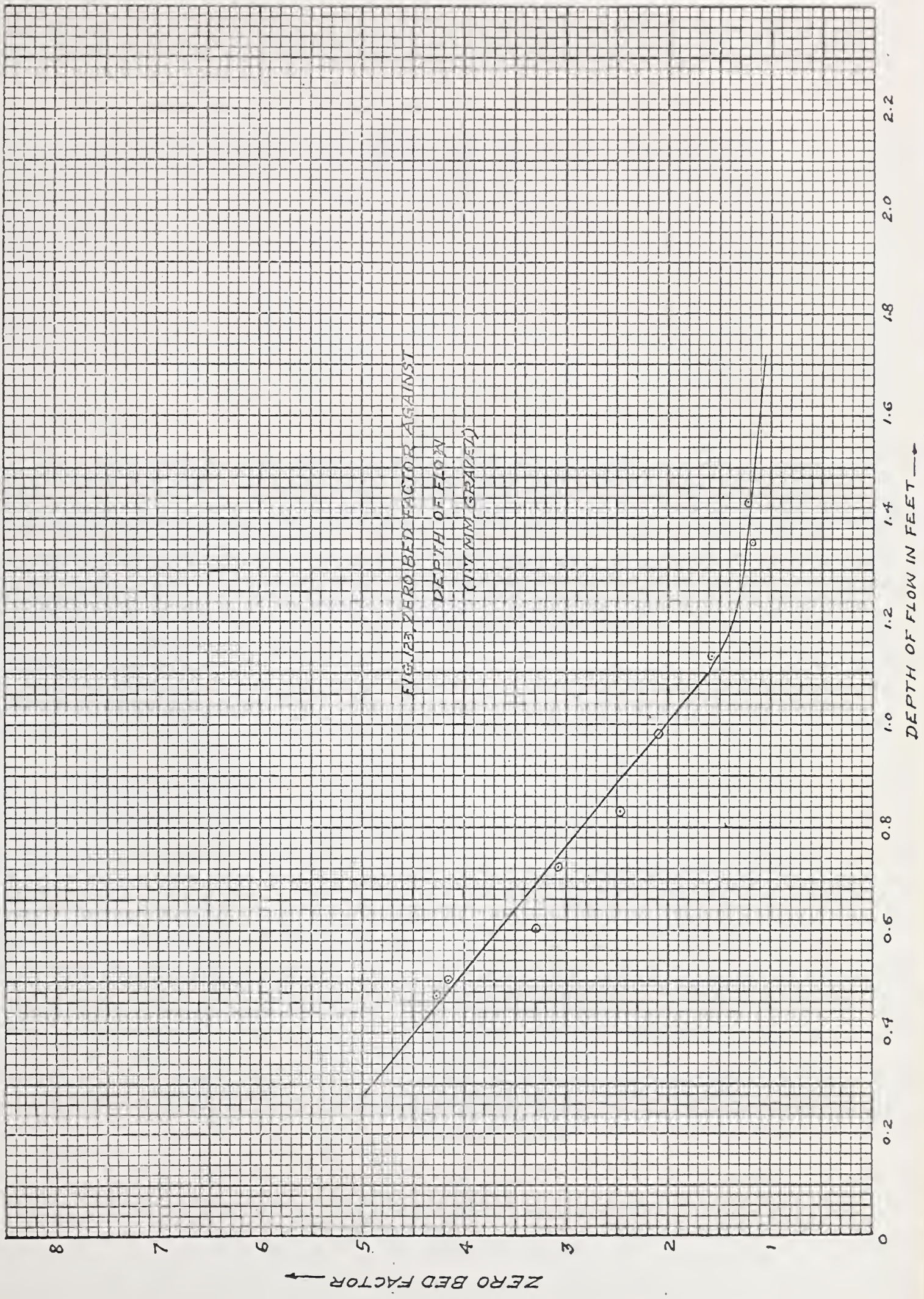


FIG 119 PROFILE SHEET [illegible]23


2694
93
92
91
90
89
88
87
86
2686.5
ELEVATION IN FEET
1000×
123
124
125
126
127
128
129
130
131
132
133
134
135
DISTANCE IN FEET
A 36
2
FIG 120. PROFILE SHEET NO: 24
EXPLANATION:
R.H. WATER SURFACE \ LOOKING
L.H. WATER SURFACE / DOWNSTREAM
SLOPE STATION No:
CROSS SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL


FIG 121. PROFILE SHEET NO. 25
EXPLANATION:
R.H. WATER SURFACE } LOOKING
L.H. WATER SURFACE } DOWNSTREAM
2. SLOPE STATION No:
A36 CROSS-SECTION No:
NOTE: ELEVATION DATUM IS MEAN SEA LEVEL
A36
A37
89
88
87
86
85
84
83
82
ELEVATION IN FEET
125
126
127
128
129
130
131
132
133
134
135
136
137
DISTANCE IN FEET
2681
1000 x


FIG. IRREGRO BED FACTOR AGAINST DISCHARGE
(1/1 MIX GRAVEL)
DISCHARGE IN CFS
ZERO BED FACTOR
0
1
2
3
4
5
6
7
8
9
10
11
12
8
7
6
5
4
3
2
1


FIG 123, ZERO BED FACTOR AGAINST
DEPTH OF FLOW
(TURNING GRADE)
ZERO BED FACTOR
DEPTH OF FLOW IN FEET
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
1
2
3
4
5
6
7
8

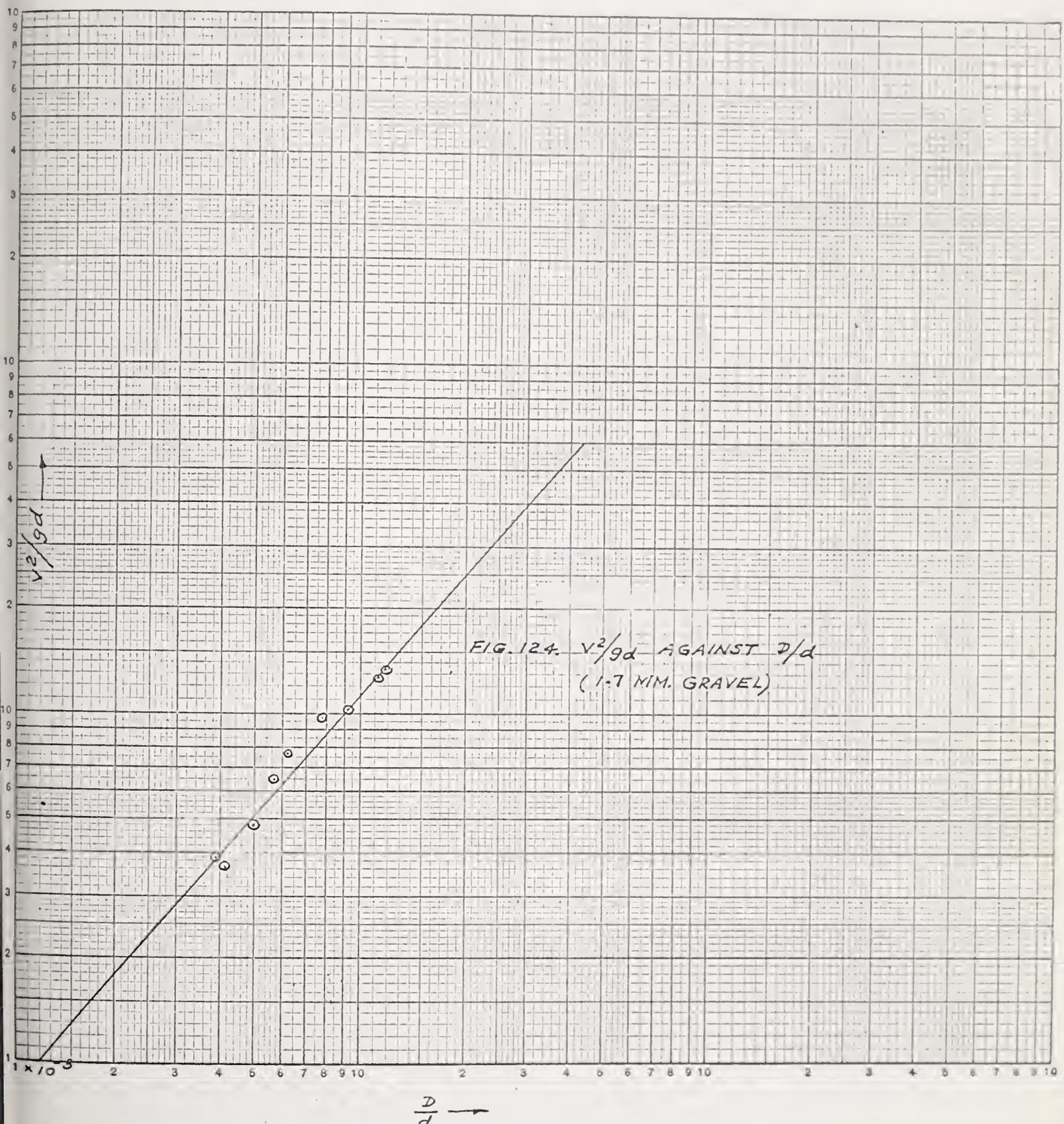


FIG. 124. V^2/gd AGAINST D/d
(1·7 MM. GRAVEL)

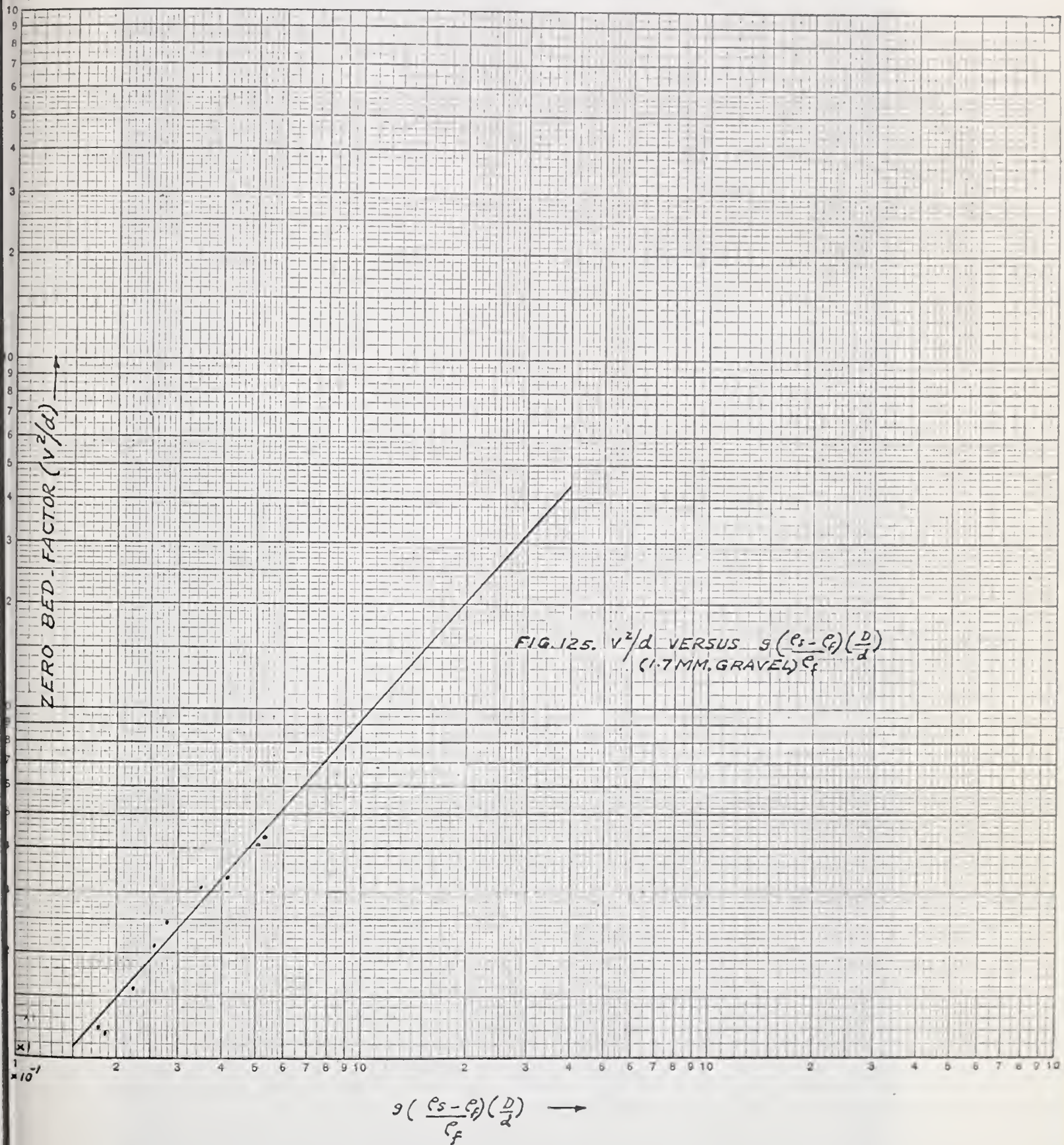


FIG. 125. V^2/d VERSUS $g\left(\frac{\rho_s-\rho_f}{\rho_f}\right)\left(\frac{D}{d}\right)$ (1·7 MM. GRAVEL)



Fig. 126 - Bed-load sample of cross-section A_2 .



Fig. 127 - Bed-load sample of cross-section A_3 .



Fig. 128 - Bed-load sample of cross-section A_5 .



Fig. 129 - Bed-load sample of cross-section A_8 .



Fig. 130 - Bed-load sample of cross-section A_9 .

JUN · 62 ·



Fig. 131 - Exposed bed between cross-sections A_3 and A_4 .



Fig. 132 - Left hand bank near A_2 looking downstream.

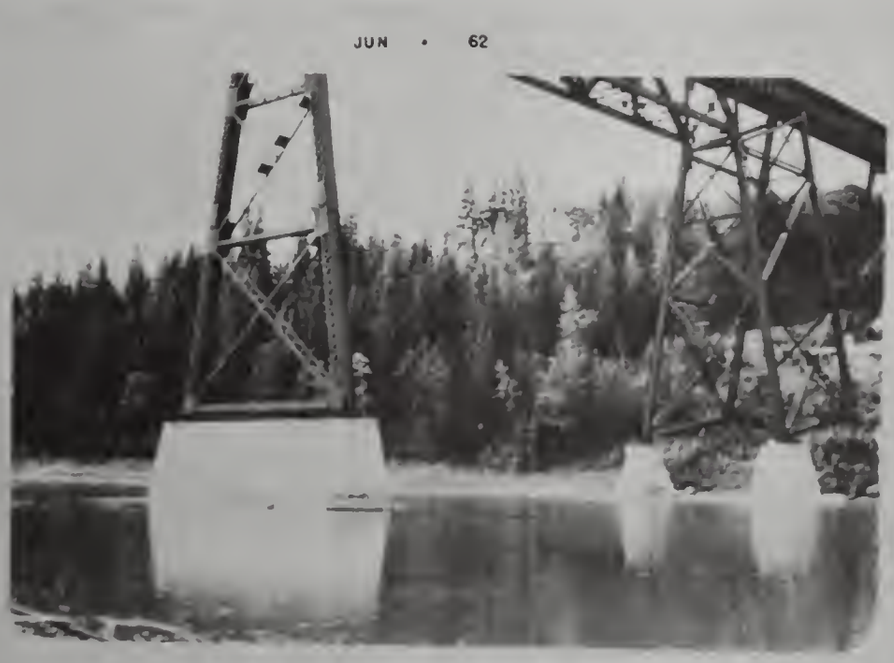


Fig. 133 - Central pier of the railway bridge and left hand bank near A_2 looking upstream.



Fig. 134 - Left hand banks looking downstream near A_7 .



Fig. 135 - Left hand banks between A_8 and A_9 looking downstream.

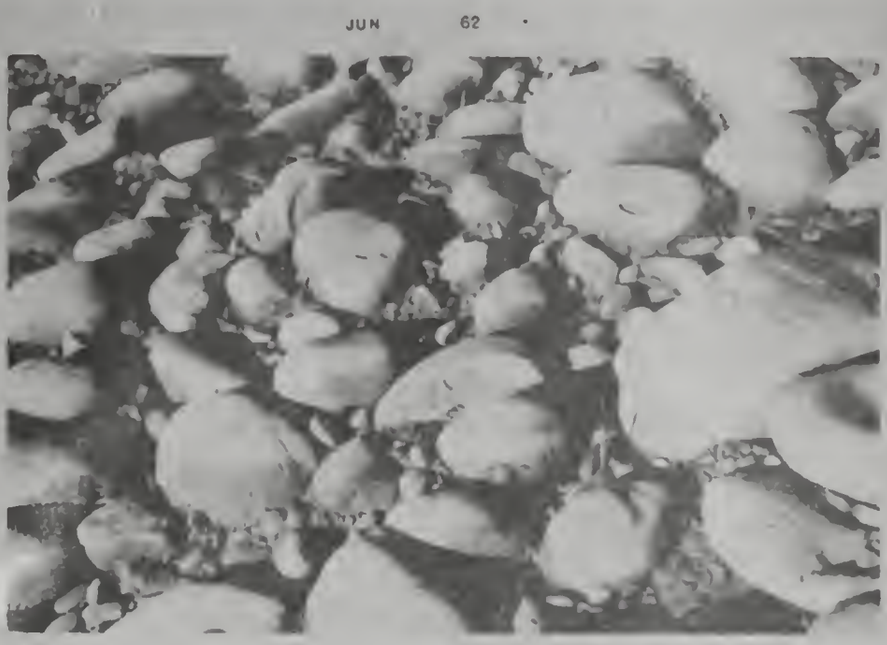


Fig. 136 - Exposed bed material downstream of Red Deer highway bridge.



Fig. 137 - Red Deer highway bridge looking upstream.



Fig. 138 - Left hand banks near A_8 looking downstream.



Fig. 139 - Highway and railway bridges at Red Deer looking upstream.



Fig. 140 - General view, near A_{16} looking downstream.



Fig. 141 - Right hand banks near A_{17} looking downstream.



Fig. 142 - Right hand banks near A_{18} looking downstream.



Fig. 143 - Right hand banks near $A_{..}$ looking upstream



Fig. 144 - General view of the river near A_{13} .

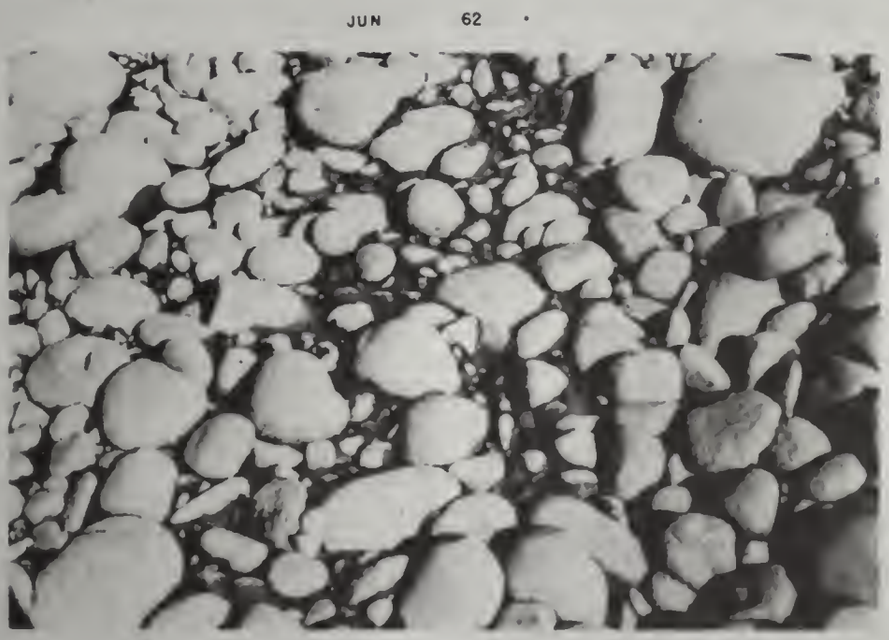


Fig. 145 - Exposed bed material near A_{14}.



Fig. 146 - Bed material (upstream of A_{24}). Exposed due to receding of water.

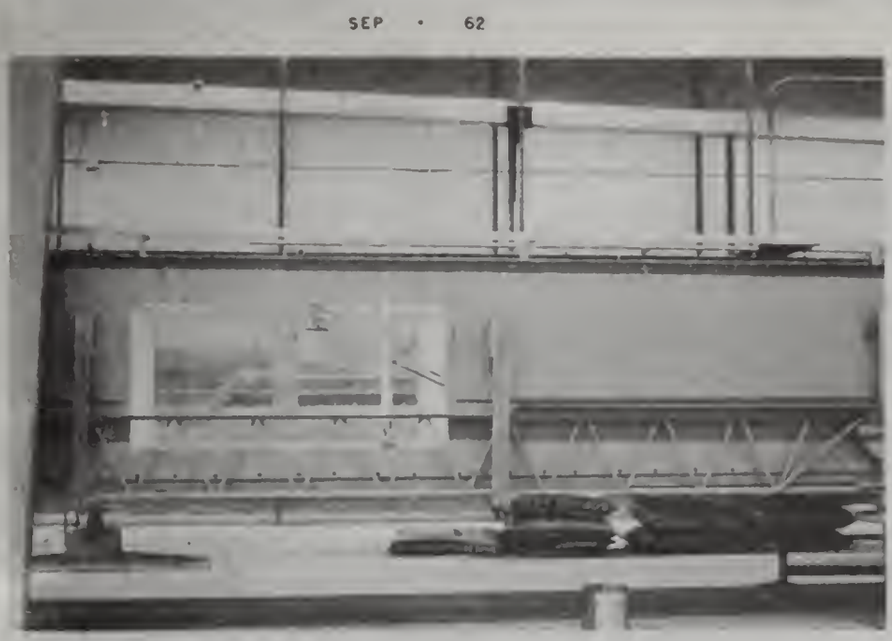


Fig. 147 - The flume.



Fig. 148 - The flume.

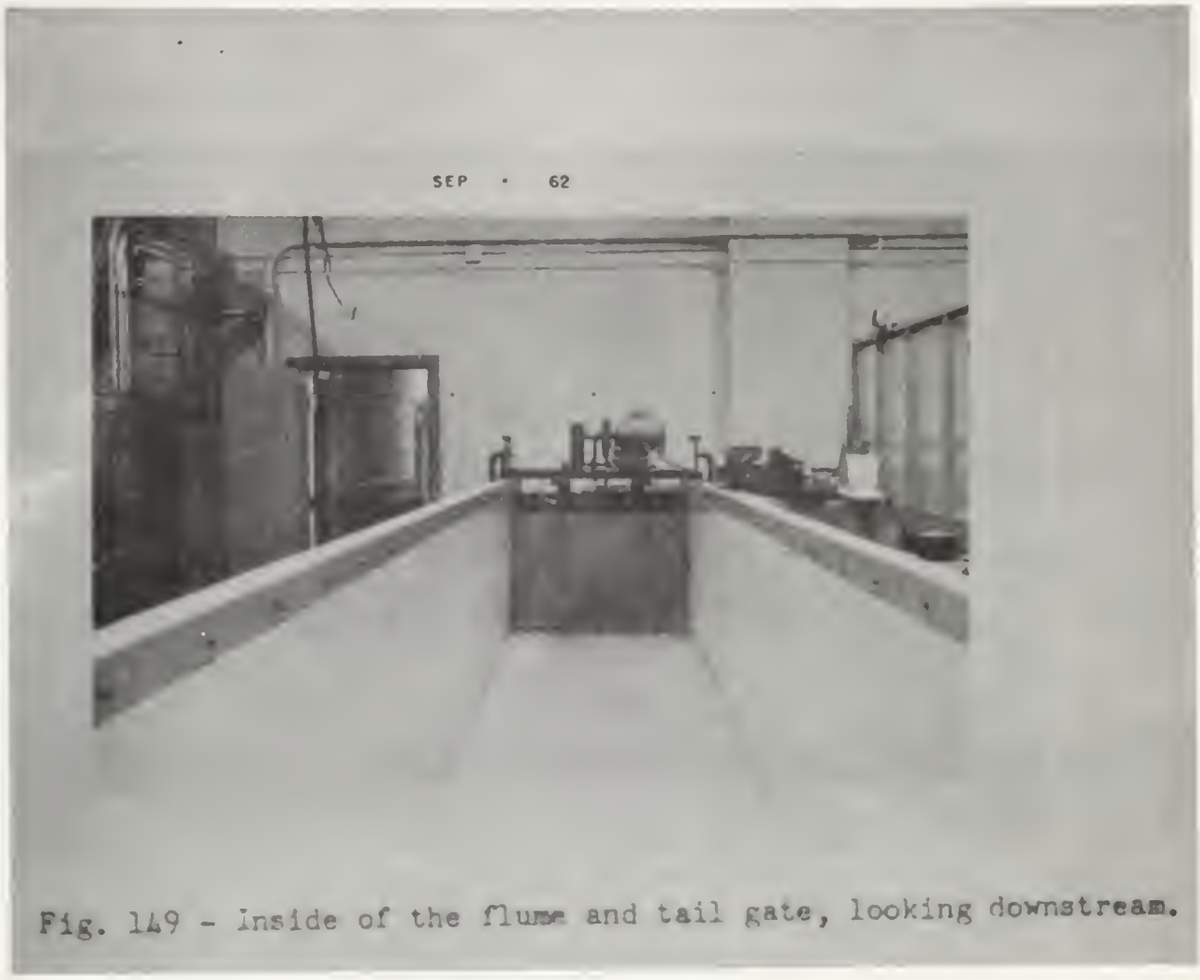


Fig. 149 - Inside of the flume and tail gate, looking downstream.

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